MISSISSIPPI HYDRO-ELECTRIC DEVELOPMENT AT KEOKUK IOWA

General Electric Company
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POWER AND MINING DEPARTMENT

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THE MISSISSIPPI RIVER HYDRO-ELECTRIC DEVELOPMENT AT KEOKUK, IOWA*

The huge hydro-electric development of the Mississippi River Power Company at Keokuk, Iowa, is one of the largest that has ever been undertaken in this country and unquestionably ranks highest among the plants of its kind in the world. It is located at the foot of the Des Moines Rapids, a dam having been constructed across the river between the cities of Keokuk, Iowa and Hamilton, Illinois, and the power house erected on the Iowa side.

Historical Review of Development

The history of the project of developing power from the Des Moines Rapids dates back as far as 1848, but no success attended the various attempts until in 1899, when a final effort was made by the citizens of Keokuk and Hamilton. The Keokuk and Hamilton Water Power Company was organized with a capital of about $2500, which was raised by the sale of stock. The city councils of Keokuk and Hamilton were applied to for help, and by unanimous consent of the citizens $7500 was appropriated and turned over to the promoting company, every cent of which has been paid back to the city treasuries. With these funds at their disposal further investigations were carried on, and Congress was applied to for a franchise, which was granted early in 1905 after a thorough investigation to safeguard the rights of the people. In the early part of 1910 sufficient capital had been assured, and the actual work on the construction was started on January 5, 1910, just thirty days before the franchise expired. The Mississippi River Power Company was formed in the spring of 1911 to succeed the old Keokuk and Hamilton Water Power Company, and is now the owner of the entire plant and equipment. Current was delivered to St. Louis on July 1, 1913, as provided by contract made long before this water-power development was even an assured project. The total cost of the development was approximately $25,000,000.

"Sacred to the Memory of Keokuk, Distinguished Sue Chief, Born at Rock Island in 1788, Died in April, 1848"

General Features of the Plant

The ultimate capacity of this development will be 300,000 horse power. The present power house installation comprises only one-half of the ultimate equipment, although the substructure of the building is complete for the second section, which will be erected as soon as the demand for additional power warrants it.

The electric power will be used mainly for manufacturing and agricultural purposes. The power zone is expected to cover a territory around Keokuk having a radius of about 200 miles and a population of over five million people according to the latest census report. The cities of Keokuk, Fort Madison, and

* Reprinted from articles by Eric A. Lof in GENERAL ELECTRIC REVIEW for February and April, 1914.

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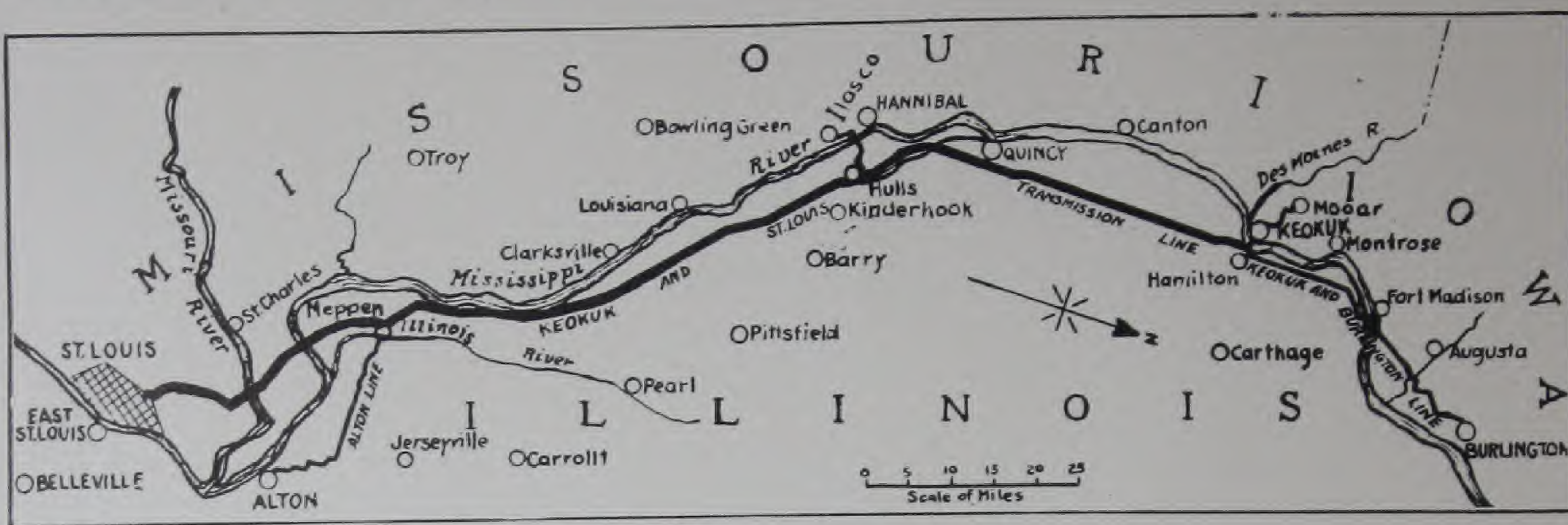


MAP OF COUNTRY SERVED BY KEOKUK DEVELOPMENT

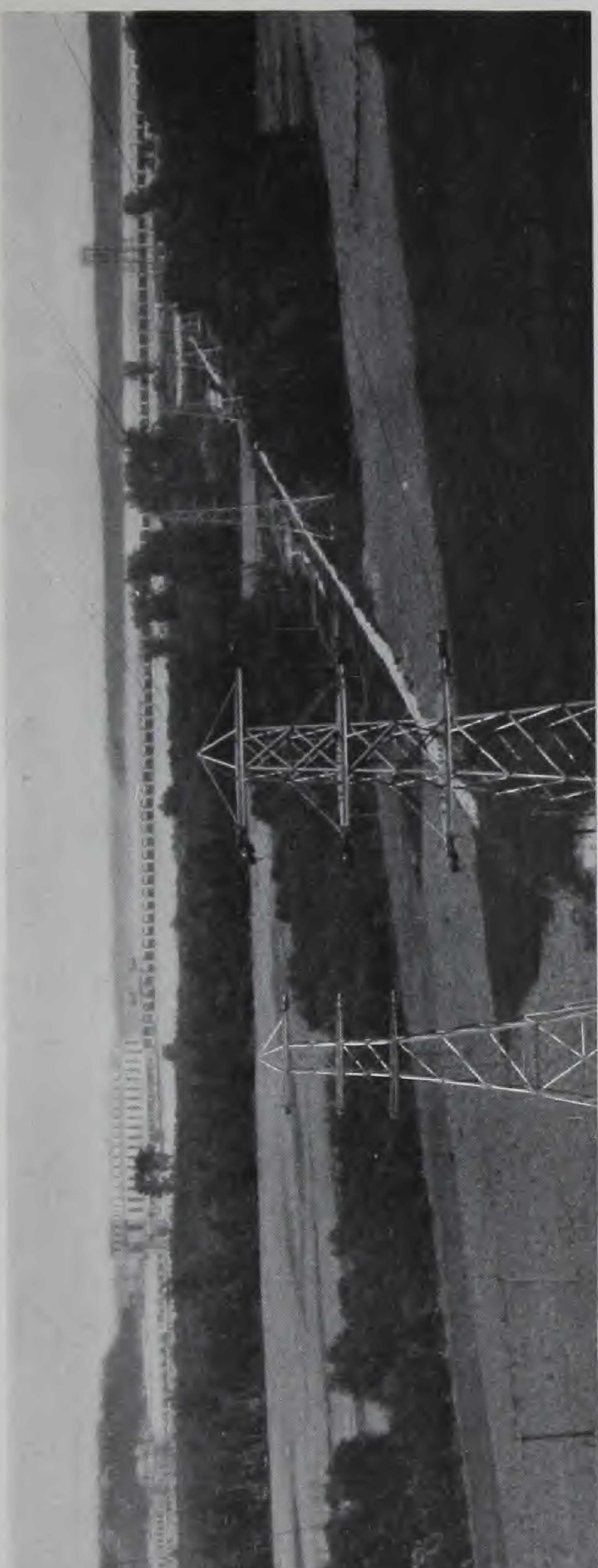
Burlington in Iowa; Hamilton, Quincy and Alton in Illinois; and Hannibal and St. Louis in Missouri, are in the territory receiving power from this system.

Several transmission lines have been erected, one 110,000 volt line covering the territory along the river as far south as St. Louis, 144 miles from Keokuk; one 66,000 volt line from Meppen to Alton; two 33,000 volt lines, one to Hannibal and one to Quincy; and one 11,000 volt line covering the territory up the river to Burlington. The bulk of the power is at present disposed of in St. Louis, where 60,000 horse power is contracted for on a 99-year lease. All the power will be disposed of wholesale to large consumers, independent distributing companies, who may tap the main transmission lines through conveniently located substations.

The plant consists of the dam across the river, the power house, a navigation lock and dry dock, a retaining wall for protecting the railroad tracks, and an ice fender—all one concrete mass with a total linear length of 2½ miles.

One of the restrictions made by the Government when granting the franchise was that a deep waterway must be maintained, the old locks, dry dock and canal being submerged under many feet of water with the new development. A lock and dry dock had therefore to be built by the water power company and ceded free of cost to the Government, which will have complete ownership of them. The lock, which is 400 feet long and 110 feet wide, is one of the largest in existence, the width being

FIRST BOATS TO GO THROUGH NEW LOCK



HYDRO-ELECTRIC DEVELOPMENT AT KEOKUK ON THE MISSISSIPPI RIVER, SHOWING DAM, POWER HOUSE AND SHIP LOCK
UPPER VIEW SHOWS TRANSMISSION TOWERS OF THE ST. LOUIS LINE

the same as that of the Panama locks. Power for operating both the lock and dry dock, as well as the machine shops, is also furnished free from a separate turbine-driven air compressor plant built by the Company and turned over to the Government.

DOWNSTREAM SIDE OF DAM

Dam

The dam is of the gravity type, built of mass concrete without reinforcement and keyed down into the limestone bottom of the river about five feet. The structure, including the east and west abutments, has a total length of 4649 feet, a width of 29 feet at the top and 42 feet at the bottom, and a height from the bottom averaging about 53 feet. It comprises 119 equal spans, consisting of arches supported on piers between which the spillway sections are placed. The structure therefore acts both as a bridge and dam, with the water flowing over the spillways beneath the arches. The piers are 6 feet wide and the spillway sections 30 feet long and about 32 feet high.

In designing this dam the extreme variations in the stream flow of the river had natur-

VIEW OF DAM AND GATE CRANE

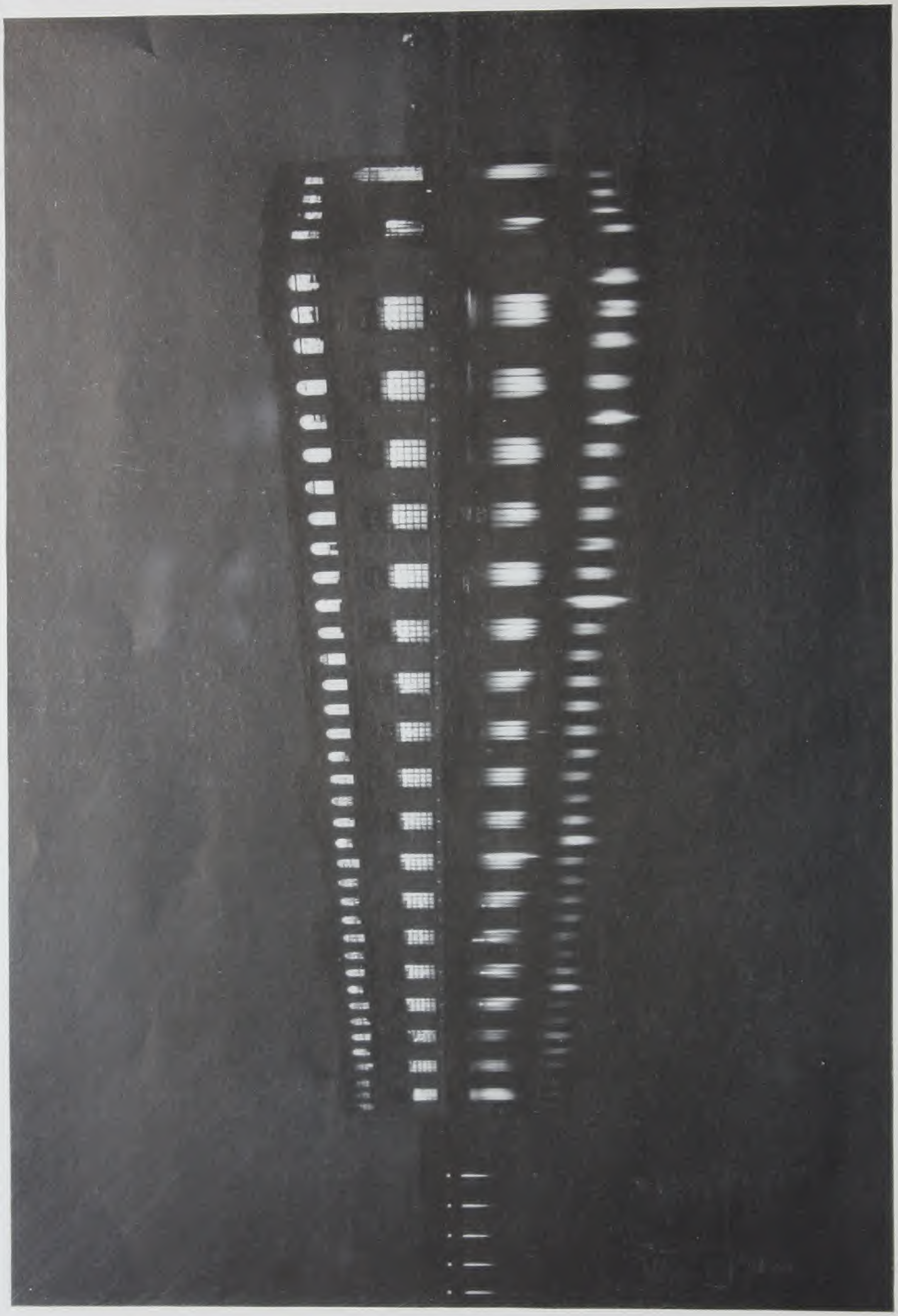
ally to be provided for, this varying from a minimum of 20,000 cubic feet per second to a maximum of 372,500 cubic feet, according to records taken during the last twenty years. While the normal operating head is 32 feet, this will vary from 21 to 39 feet from high to low water.

TIMBER COFFERDAM FOR POWER HOUSE RESISTING ICE JAM, MARCH 24, 1912. COFFERDAM 25½ FEET HIGH

It was also necessary to limit the water level above the dam to prevent flooding of such land as had not been included in the flowage lands. The height of the spillway has therefore been designed to take care of the limit of the upper level. Furthermore, in order to keep the water above the dam at constant level with smaller flow, steel gates have been provided on top of all the spillways. In extreme high water periods these gates will all be open, while at lower stages a sufficient number will be closed to maintain the pool above the dam at the proper level.

The spillway gates are built of steel truss framework faced with steel plates, and they are raised or lowered by means of two electrically operated derricks, traveling on a track on top of the dam. Two standard gauge railroad tracks previously used for construction are also located on the dam and serve the above mentioned gates.

POWER HOUSE



THE POWER HOUSE AT KEOKUK BY NIGHT

The erection of this dam across the Mississippi River at Keokuk has formed a lake which covers an area of approximately 43,000 acres. It extends 65 miles upstream to Burlington, Iowa, and varies in width from one to three miles. Navigation for this distance, which formerly was very difficult during low water periods, has therefore been greatly benefited.

Power House

The power house is located some distance from the Iowa shore, the intervening space forming the forebay. It lies almost parallel with the river, and the water runs through the intakes and draft tubes nearly at right angles to the river flow, resuming its normal direction in the tail race, which is excavated in the river bed from the upper end of the power house along its entire length and for some distance beyond the downstream end.

The total length of the power house will be 1708 feet, of which the portion normally submerged is now completed. It consists essentially of two distinct parts, the substructure and the superstructure. The former not only serves as a foundation for the present part of the power house superstructure, but is in reality the hydraulic structure of the building. It has been completed to its full height on the forebay side for the entire plant, including the future extension, while on the river side the downstream half has been built above high water. It includes, however, the draft tube openings for the future units.

The width of the building is 132 ft. 10 in., and the total height 177 ft. 6 in., of which the height of the substructure to the generator floor is 70 feet and to the transformer floor 78 feet. The height of the generator room is 68 feet, which gives ample head-room for the traveling cranes, and makes it possible to take out the turbine runners with their shafts and carry them to the repair shop at the end of the generator room.

To gain head, and in order that the draft tubes might always be covered with water,

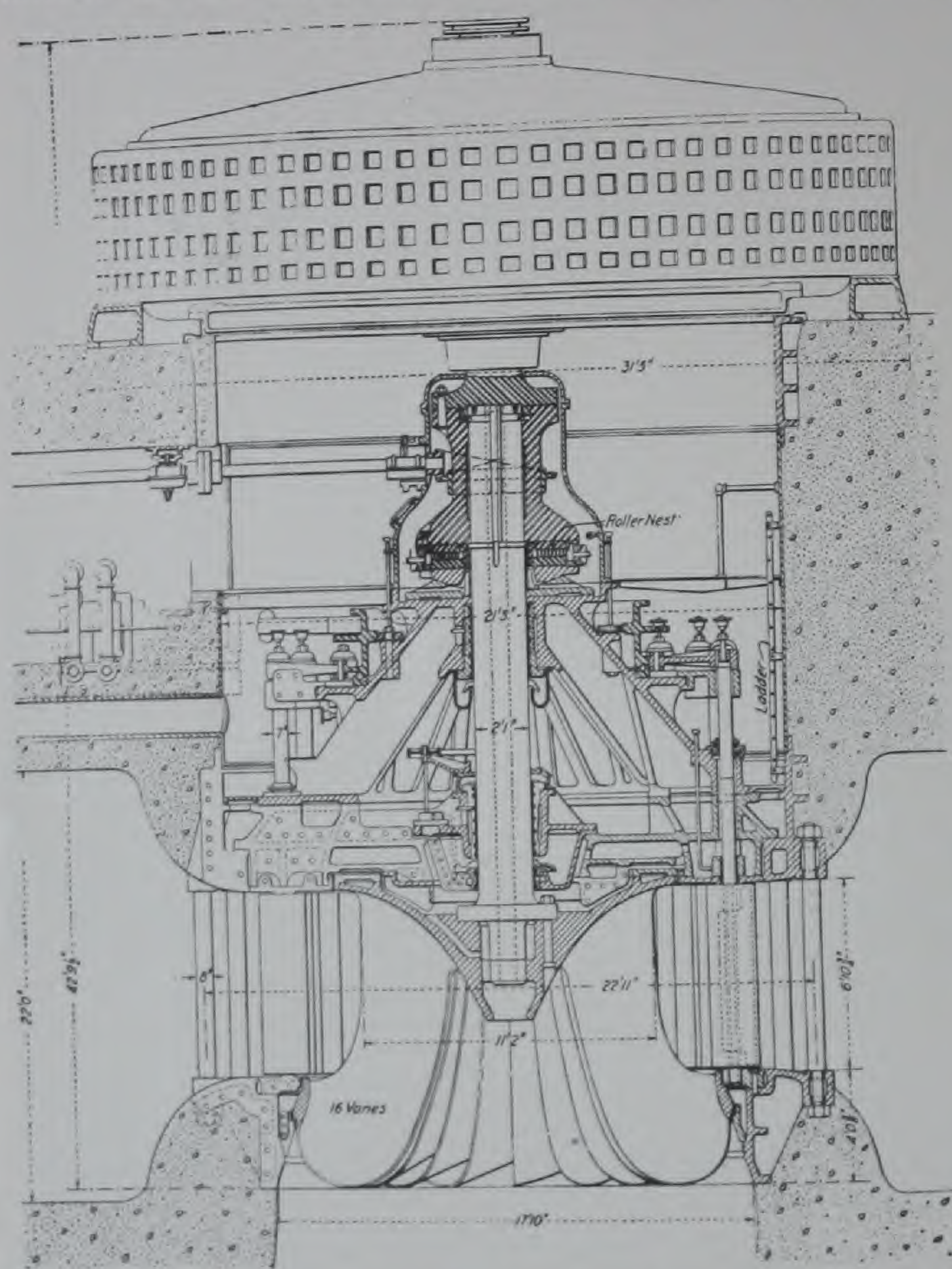
LOOKING SOUTH THROUGH GATE ROOM, SHOWING GATE MECHANISMS IN PLACE

the power house foundation has been extended down in the bed-rock of the river about 25 feet below the limestone bottom. The substructure is built entirely of concrete, the intake, scroll chambers and draft tubes being moulded in. It contains 211,400 cubic yards of concrete, or 13,400 cubic yards more than was used for the dam.

The superstructure is a reinforced concrete building of imposing design, containing four floors. The generator room is located on the main floor along the river side. The exciter sets and transformers are installed in compartments in the center of the building, while the gateroom occupies the shore side of the building. The floor level for the exciter, transformer and gaterooms is 8

feet higher than the floor of the generator room.

For the low tension switches, busbars and reactances, there are provided two narrow mezzanine floors in the center of the building. Except at the ends, where additions are built out over the generator room to accommodate offices and store rooms, the fourth floor extends for the entire length of the building on the shoreward side only. This floor contains the switchboard control room, the 110,000 volt switches, busbars and lightning arresters.



SECTIONAL ELEVATION OF TURBINE SHOWING THRUST BEARING AND CONNECTION TO GENERATOR SHAFT

The floors are supported partly on steel trusses and partly on concrete beams, interconnecting four rows of columns which rest on the substructure and extend to the roof. The floors and roof are of reinforced concrete slabs, a large portion of the floors being covered with red tile, while the roof is covered with tar and gravel. Window sashes and frames are all of steel, the windows being electrically operated. The lower part of the interior walls are painted dark green, while the finish of the upper part is white or cream. The entire exterior surface of the building is finished with white cement wash.

HYDRAULIC EQUIPMENT

Intakes and Scroll Chambers

From the forebay the water enters each turbine through four intakes converging into a scroll chamber moulded in the concrete around the turbine. The design of this spiral-formed scroll chamber and the intakes has been made very carefully in order to insure an equal velocity and force of the water all around the circumference of the wheel and thus obtain the highest efficiency possible. Three of the intakes for each turbine are entirely separate from the fourth, uniting in a common passage, some distance from the scroll chamber for passing the water to the further side of the wheel, while the fourth intake supplies the water to the nearest side. The scroll chamber has an average diameter of 39 feet and a height of 22 feet.

The outer openings of the intakes, which are 7½ feet wide by 22 feet high, are provided with steel gates sliding in cast iron guides. For raising these gates, as well as the screens, a 75-ton traveling crane is provided, running the full length of the gate house. For lower-

ing the gates, however, there are separate brake mechanisms for each gate.

Draft Tubes

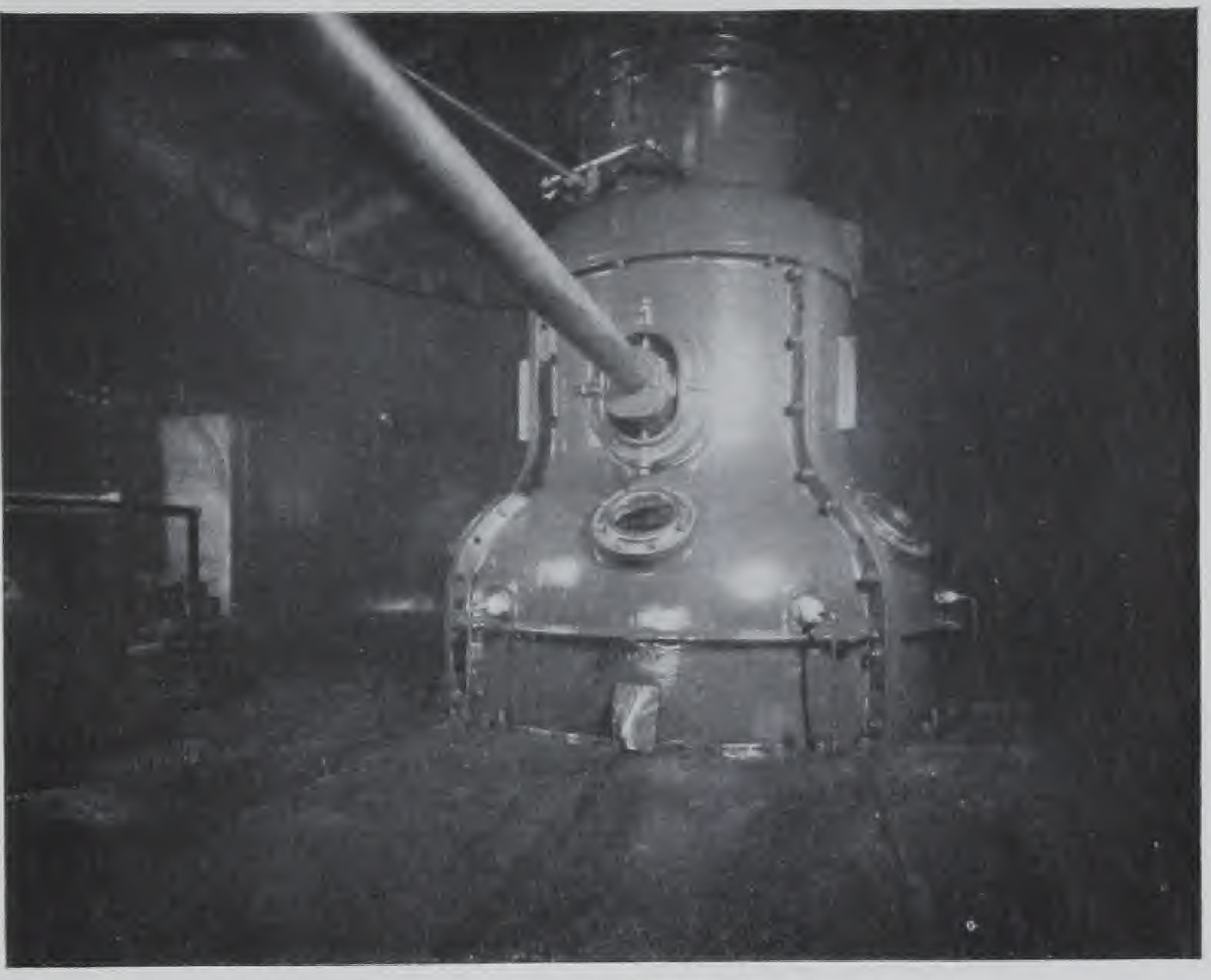
The water from the turbines is discharged to the tail race through concrete draft tubes. These are about 60 feet long, gradually curved from a vertical to a horizontal direction. The foundations at their outlets are about 25 feet below the normal river bed. The draft tubes have a diameter of 18 feet at the wheels, but their cross-section changes from a circular section at this point to an oval shape at the outlet; the tail race openings measuring 22 feet 8 inches in height by 40 feet 2 inches in width. This enlargement and change in shape is calculated to reduce the discharge velocity of the water.

Main Turbines

The initial installation comprises fifteen main turbines of the vertical single runner Francis type. They have a normal rating of 10,000 h.p. based on a head of 32 feet. Their design is, however, such that they will operate efficiently with a head varying from 21 to 39 feet. The actual speed is 57.7 r.p.m., the specific speed 338, and the maximum efficiency at normal head about 88 per cent.

The turbine itself is placed at the bottom of a large concrete-encased steel cylinder called the pit liner. Bolted to the upper and lower ends of this steel shell are large cast iron rings, weighing 30 to 40 tons each, which support the entire weight of the unit, or approximately one million pounds. Each turbine has twenty cast steel guide vanes, which are placed just below the pit liner cylinder between the two heavy cast iron foundation rings, which are separated by 8-inch bolts.

Each runner has 16 vanes, the outside diameter at the bottom being approximately 17 ft. and at the top 12½ ft., the length being 11 ft. The runner is mounted on a forged steel shaft, which has a diameter of 25 inches and is coupled to the generator shaft above. The weight of each runner alone is 64 tons, while the weight of the total revolving element, including the water thrust and the generator field, is 275 tons. This weight is carried by a thrust bearing at the top of the wheel and below the generator, the bearing being supported from the upper foundation ring. Two guide bearings are also provided for each turbine unit.



STEP BEARING FOR MAIN GENERATOR

Two different kinds of thrust bearings are used. Twelve of the units are equipped with the Standard Roller Bearing Company's combination oil-pressure and roller bearing. Under normal operation oil is forced between the two bearing faces at a 225 pound pressure, separating these by a thin film of oil, on which the revolving element is supported. However, if for any reason the oil pressure or supply should fail, the upper bearing plate will settle down on a set of oil-immersed steel

rollers, which will then carry the weight of the rotating element without interrupting the operation. The three remaining thrust bearings are of the Kingsbury type, and require lubrication at only atmospheric pressure.

For lubricating the pressure type thrust bearings, each unit is provided with a separate triplex oil pump, chain driven from the governor shafts and having a capacity of 150 gallons per minute at 225 lb. pressure. A central oil supply system for the thrust bearings is also installed to be used in case of emergency. This consists of two motor-driven triplex oil pressure pumps, located in the main pump room and piped to the different bearings.

The lubricating oil for the guide bearings is furnished either by two waterwheel-driven or two motor-driven pumps. The oil is pumped to large tanks, whence it flows by gravity to the bearings and thence to reservoirs under the lower bearings. From the reservoirs it is pumped to the filtering and central supply tanks. Provisions are also made so that the oil can be simultaneously pumped directly to the bearings and the gravity tanks.

Revolving indicators, designed on the principle of water meters, are inserted in the piping leading to the guide bearings of each unit. These indicators are so adjusted that a certain number of revolutions correspond to a certain quantity of oil. Thermometers are also inserted in the in and outgoing oil supply pipes for each unit.

Auxiliary Turbines

In addition to the main units there are two smaller turbines for driving the auxiliary generators furnishing power to the motor-driven exciters. These turbines, which are also of the vertical type, have a capacity of 2200 h.p. and a speed of 125 r.p.m.

Governors

The regulation of each turbine is accomplished by a specially designed Lombard oil-pressure governor, the balanced guide vanes being controlled through an exposed operating mechanism from the actuators, which are located on the generator floor in front of each unit. The operating mechanism consists of a rocker ring, which is carried on ball bearings and which is connected by links to the cranks on the guide vane stems. The rocker ring is operated by means of piston rods from two high-pressure regulating cylinders, which, together with the relay valves, are located on the thrust bearing floor. Under 200 lb. oil pressure these cylinders will develop 250,000 ft.-lb., and the oil pressure is furnished by a separate induction motor-driven triplex pump for each unit. This pump and motor, as well as the accumulator and receiving tanks are also installed on the thrust bearing floor. By means of an automatic control arrangement the pump is started up if the pressure falls below 140 lb., and continues to run until it has reached 180 lb. The speed control element and the anti-racing devices are installed in the governor pedestals on the main floor, and the governor fly balls are driven mechanically from a countershaft which is geared direct to the turbine shaft. On the governor pedestals are further mounted various gauges indicating the oil pressure, the gate opening, and the speed, while provisions are made so that the automatic regulation can be changed over to hand control if desired. The governor mechanism is also equipped with a motor connected electrically to the control switchboard, in order that the switchboard operator shall be able to control the speed of any unit when synchronizing.

The governors are guaranteed to maintain the speed steady within one-half of one per cent, and on decrease of load to bring the speed to normal within five seconds.

ELECTRICAL EQUIPMENT

System of Connections

The system of connections has been laid out with a view of securing the greatest flexibility and reliability, and double sets of

busbars are therefore installed on both the high and low tension sides. As seen from the wiring diagram, one of the low tension busses runs continuous for the full length of the station, and this set will normally be used for forming a ring-connection or for transfer purposes in case of emergency. The generators will be normally connected to the other bus, which is divided into five sections, with current-limiting reactances and sectionalizing switches inserted between sections.

Both high-tension busses are divided into two sections, the operating bus being provided with sectionalizing switches; and while these will be open under normal operation, they afford means of paralleling the sections if desired. The other set is intended for transfer of the transformers within the respective sections only.

The two 110,000 volt outgoing St. Louis circuits are connected to sections "A" and "B," while the two 11,000 volt Burlington circuits are fed from section "D." The station and local service is taken from sections "C" and "E." However, when the demand for power increases, it is the intention to run two 110,000 volt lines from sections "C" and "D." In this manner the generators and transformers feeding each outgoing line will be on a separate section, insuring against trouble caused by short circuits or surges spreading from one section to the other.

Arrangement of Apparatus

The fifteen main generators are located directly above the turbines and are spaced along the generator room 48 feet apart, measured between the center lines of the units. The two auxiliary generators are installed between main units Nos. 8 and 9. These auxiliary generators are equipped with direct-connected exciters mounted on top of the units, while the individual exciters for the main generators are motor-driven; the sets being installed in compartments on the same floor level as the gate house floor, eight feet above the generator room floor. These exciter compartments are entirely open towards the generator room, and openings are furthermore provided in the partitions between the compartments, thus affording a continuous passage through the whole length of what may be termed the exciter gallery. The auxiliary exciter, lighting and power transformers, as well as the auxiliary switchboards, are also located in compartments on this gallery, facing the generator room.

The large main transformers are installed on the same floor level and back of the exciter sets in compartments opening towards the gate house. The low-tension busbars and oil switches are located above these compartments, as shown in the cross-section.

The high-tension room occupies almost the entire top floor of the gate room section of the building. Its floor is at the same elevation as the roof of the generator room, and it is divided into a number of compartments, or rather rooms, for separating the various high tension switches, lightning arresters, connections, etc. The outgoing lines run through roof bushings to the roof structure to which the long river spans are anchored. These roof structures also support the line disconnecting switches and the lightning arrester horn gaps, while the arrester tanks are installed on the high-tension switch room floor.

The control switchboards are located in a large room at the south end of the high-tension switch room floor—a position which ultimately will be in the center of the building when this has been extended to its full length. This room is entirely shut off from the generator room; but, by descending a short flight of stairs to an inspection gallery, a view of the entire generator floor is obtained. All the pumps for water, vacuum and air compressor systems, are located in tunnel below the transformers.

Main Generators

As previously mentioned, the present installation comprises fifteen main units. They are of the three-phase, twenty-five cycle, vertical revolving field type, having

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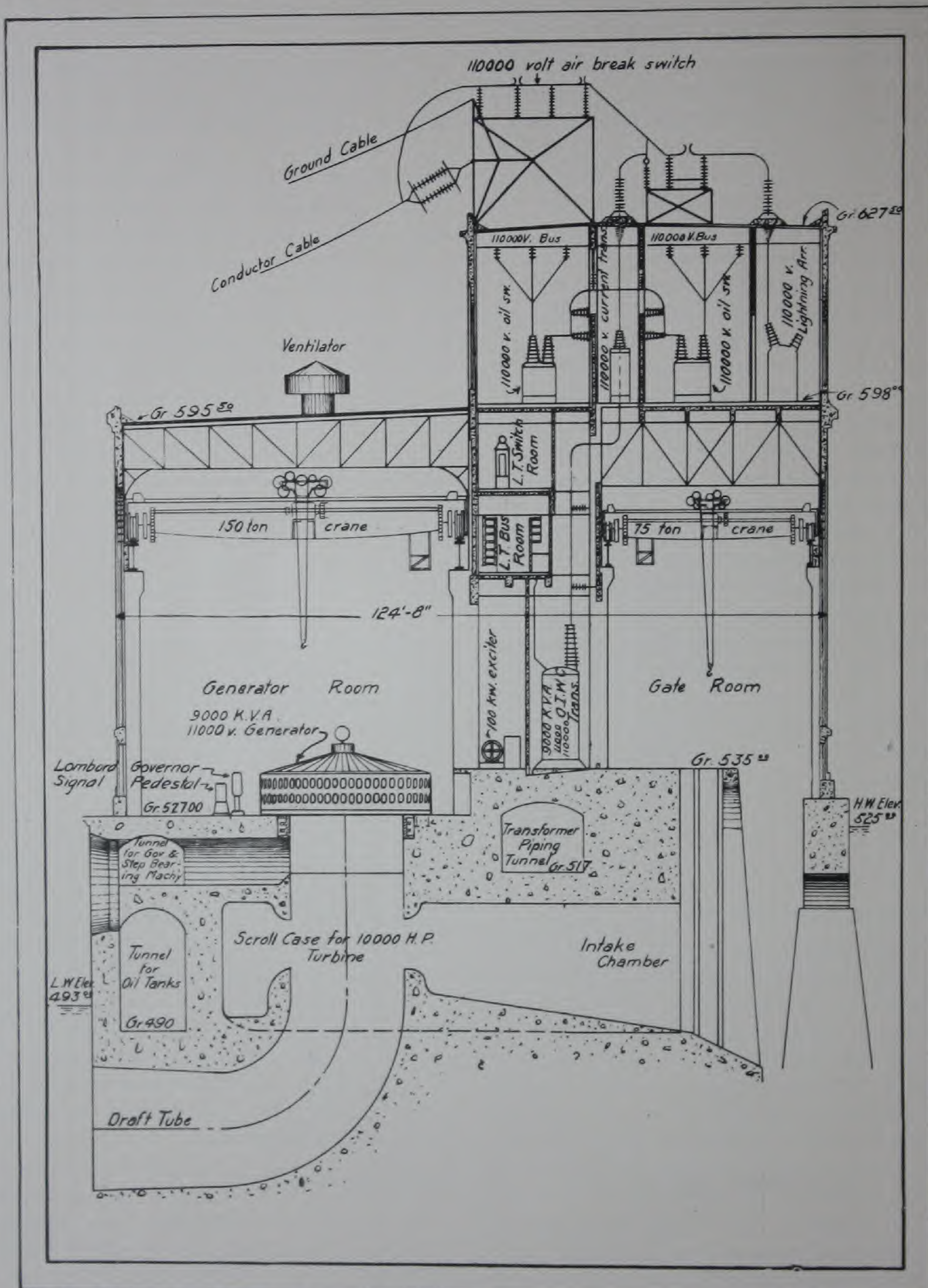
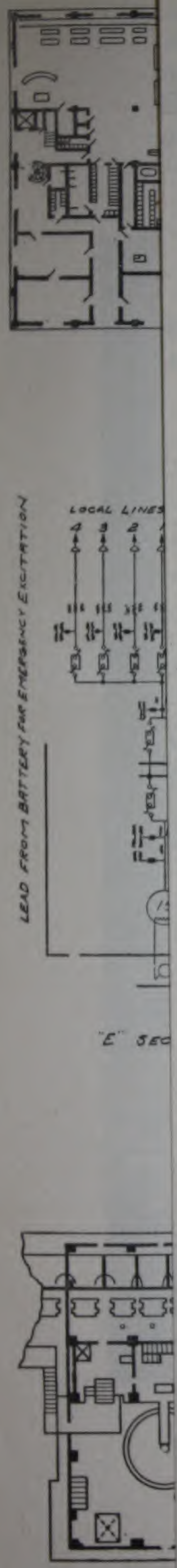


SECTIONAL ELEVATION OF POWER HOUSE


LEAD FROM BATTERY FOR EMERGENCY EXCITATION
LOCAL LINES
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3
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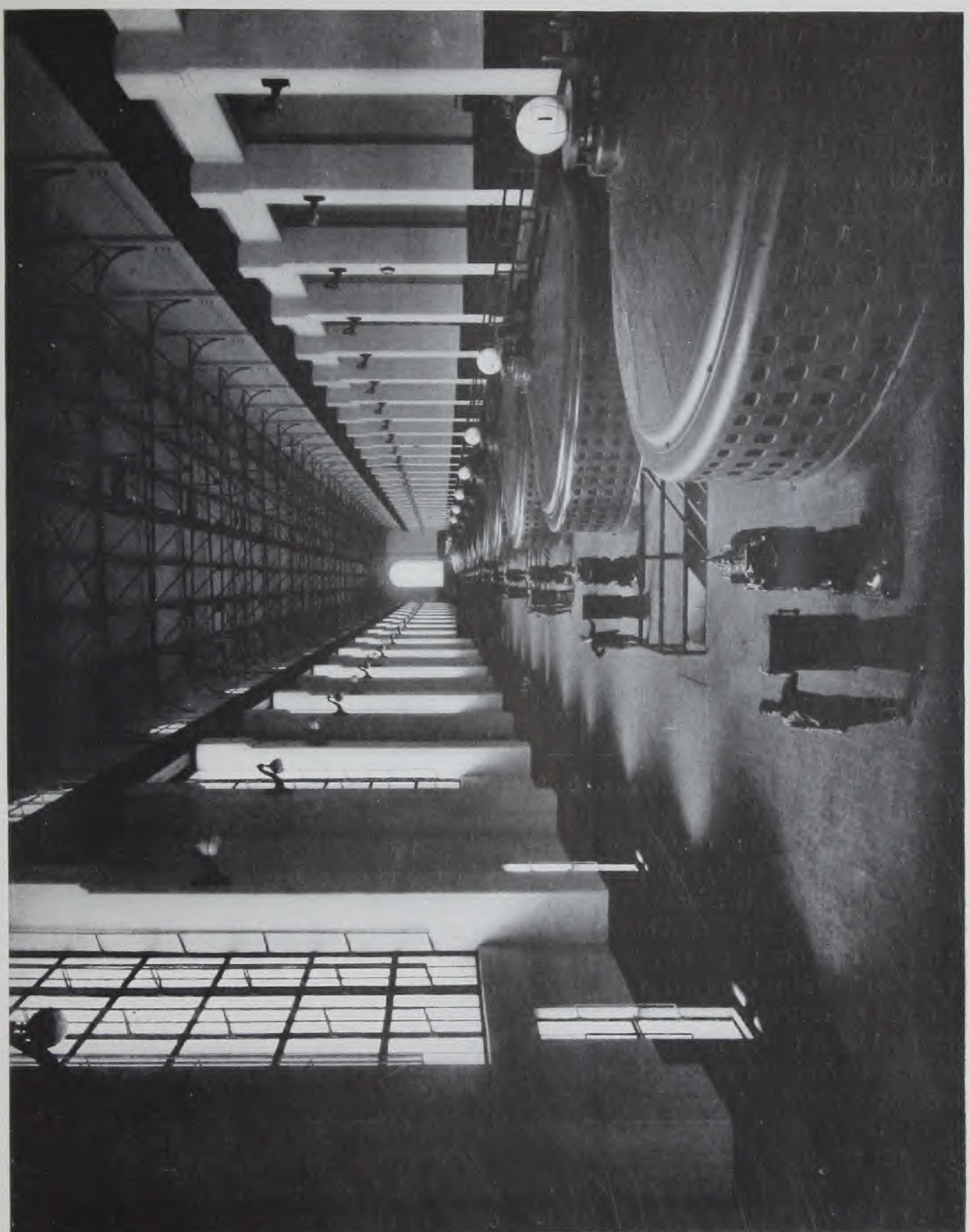


GENERATOR ROOM

52 poles and operating at a normal speed of 57.7 revolutions per minute. They have a maximum continuous rating of 9000 kv-a. at 11,000 volts, and when operating at 80 per cent power-factor the temperature rise will not exceed 50 deg. C. on the armature winding measured by resistance or temperature coils placed in the armature slots between the top and bottom coils; 50 deg. C. on the field winding measured by resistance; or 50 deg. C. on all other parts measured by thermometer.

The machines are designed for a high internal reactance, limiting the instantaneous short circuit current to about five times the normal value. At the same time they have an inherent regulation of approximately 8 per cent at unity power-factor and 20 per cent at 80 per cent power-factor.

The guaranteed efficiencies were as given in the following table, while actual tests after installation indicated even somewhat higher values:

	Full Load	¾ Load	½ Load
9000 kv-a., 1.0 power-factor	96.3	95.9	94.6
7200 kw., 0.8 power-factor	95	94.5	93

The required maximum excitation is 85 kw. at 250 volts.

The armature winding consists of form-wound interchangeable coils of the barrel type, heavily insulated with both mica and varnished cambric. They are Y-connected but the neutral is not brought out to the terminal board.

The field spider is made of cast iron with the field rim of cast steel. The pole pieces are securely bolted to the rim and the whole construction is designed to withstand a 100 per cent over speed. The flywheel effect (WR^2) of the revolving field is approximately 20,000,000 lb.-ft.

The two collector rings are mounted on the shaft extension above the top brackets. Bridges with handrails are built to the exciter gallery, thus facilitating the inspection and adjustment of the collector ring brushes. These bridges also serve as a support for the field leads which run in conduit underneath the bridge directly from the exciters to the collector rings.

Two guide bearings are provided for each generator, one above and one below the rotating field. The shaft is a hollow steel forging 27 inches in diameter, with a forged coupling, 57 inches in diameter, on the lower end for bolting to the combined coupling and thrust block on the waterwheel shaft.

For ventilating the machine, the movement of the air is brought about by the natural fanning action of the revolving field, holes being provided in the field spider rim between the poles to secure a uniform ventilation of the field coils. The air is drawn through the openings in the top cover of the frame and from the pit below, and is discharged through holes in the sides of the frame after having been forced through the ventilating ducts in the core.

Each generator is equipped with a pneumatically operated brake, consisting of eight sets of brake cylinders with shoes which work against the lower surface of the revolving field rim. These brakes are designed to bring the whole rotating element to rest in from five to ten minutes, against the water leakage which may be expected to leak through the gates. The piping to the cylinders has been laid out so that a failure to any of the sets will not affect and cripple the others.

The outside diameter of the generator frame is 31 ft. 5 in., and of the revolving field 25 ft. 5 in., while the height of the unit at the center is 11 ft. 3 in. The net weight of the stator is 221,000 lb., of the base 165,000 lb., and of the rotor and shaft 228,000 lb., the total being 614,000 lb.

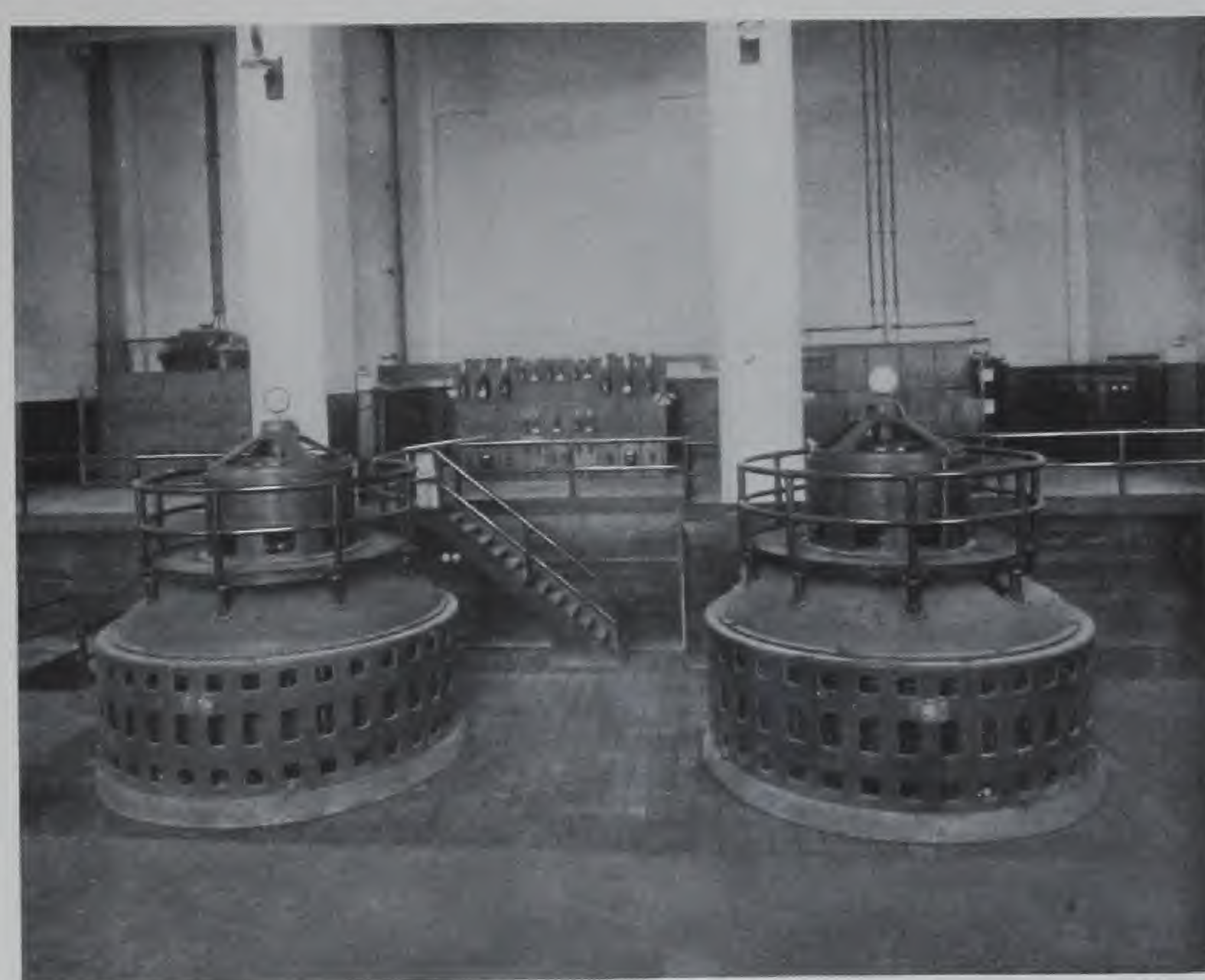
System of Excitation

The system of excitation is of unusual interest, being quite out of the ordinary. In order to obtain the greatest flexibility, each generating unit is provided with a separate exciter. These are motor-driven and operate at a much higher speed than would have been

possible with direct connected units, which results in a more economical arrangement. The exciter sets receive their driving power normally from an entirely independent source, consisting of two auxiliary waterwheel-driven alternators feeding into a set of busbars which run the full length of the station; sectionalizing switches being provided only in the middle so that if desired the bus can be divided into two sections with one auxiliary alternator connected to each. Provisions are also made so that the exciter sets can be fed from the main bus, four step-down transformers being provided for this purpose. They connect the main bus with a second auxiliary exciter bus, which is sectionalized in four groups with one transformer for each group. Connections can also be established, in case of emergency, with one of the duplicate storage batteries which ordinarily are used for the operation of the oil switches.

The two auxiliary alternators are equipped with individual direct connected exciters, and TA regulators serve to keep the auxiliary bus voltage constant. Besides supplying the exciter sets, energy is also normally taken from this bus for the power and lighting required for the station service, although provisions are made so that it can also be taken from the main bus.

The field current is conducted directly from the motor-driven exciters to their respective generators, the commutator brushes of the former simply being connected to the collector ring brushes of the latter, with solenoid operated field switches inserted in one of the leads. The regulation is accomplished by adjusting the fields of the individual exciters, thus eliminating large field rheostats and energy losses in the main field circuits. Each exciter is provided with its own TA regulator, and parallel operation with compensation for cross-currents is obtained by means of current and potential transformers which are installed in the generator leads and connected 90 degrees out of phase with each other. If cross-currents tend to flow between the generators, the regulators will reduce these by strengthening or weakening the field of the affected generators.



AUXILIARY ALTERNATORS

The two auxiliary alternators are of the vertical type direct connected to waterwheels. They have a maximum continuous rating of 2000 kv-a. at 460 volts and operate normally at 125 r.p.m. Their general design is the same as for the main units, with the exception that each is equipped with a direct connected exciter mounted on the upper bearing bracket so that the machines can be started as self-contained units. The upper bearing bracket also supports a Standard roller thrust bearing which carries the weight of the total revolving element, including the waterwheel runner and the water thrust.

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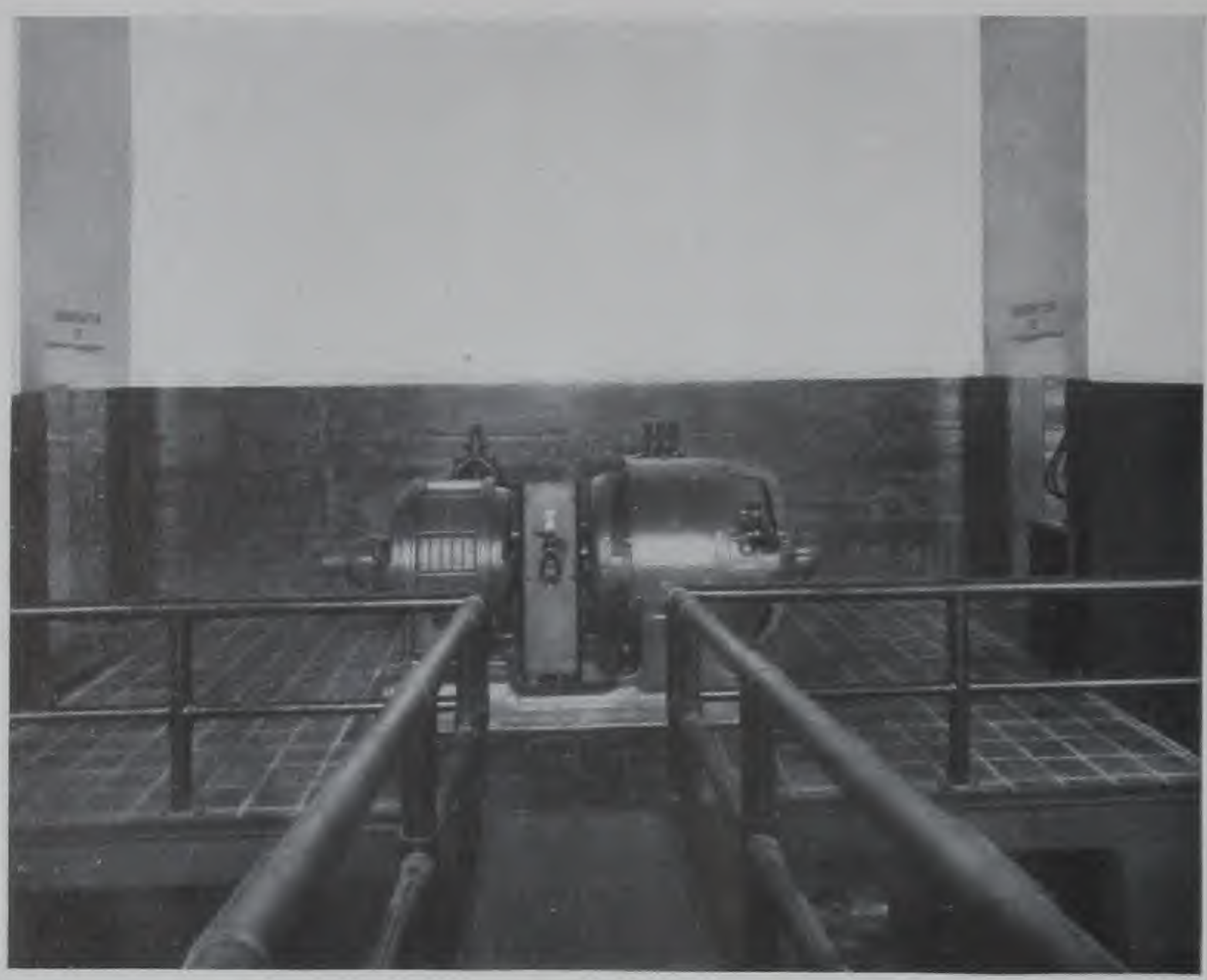
Under test these auxiliary generators showed a temperature rise well within 50 deg. C. and an efficiency of 95.1 per cent, both based on the full load of 1600 kw. at 80 per cent power-factor. At full load, with unity power-factor, the inherent regulation is approximately 8 per cent. Each unit requires a maximum excitation of about 30 kw. at 250 volts, and motor-driven field rheostats are provided so that the voltage may be adjusted from the control switchboard.



EXCITER SET

The direct connected exciters for these units are of the compound-wound, commutating pole type. They have a normal rating of 60 kw. at 250 volts, and each exciter is therefore capable of exciting both the machines in case one of the exciters should be disabled. Connections and switching arrangements are provided to accomplish this, and also to make it possible to operate the two exciters in parallel if desired.

The total weight of each auxiliary generator is 127,000 lb. and of each exciter 15,000 lb.; the combined weight of the rotating elements being 42,500 lb. The diameter is 13 ft. 8 in. and the over-all height from the floor to the top of the exciter, 13 ft. 3 in.

Each of the exciter sets for the main units consists of a six-pole 100 kw., 250 volt-shunt-wound commutating pole generator mounted on the same base with and driven by a four-pole 25 cycle, 3-phase, 440 volt squirrel-cage induction motor, the set operating at a synchronous speed of 750 revolutions per minute.

The sets are designed to operate at 25 per cent overload for 2 hours, and with a full load efficiency of 84.2 per cent. The starting is accomplished through a starting compensator. Provision is made for overload or low-voltage tripping, although not used at present. The total weight of each set is approximately 11,500 pounds.

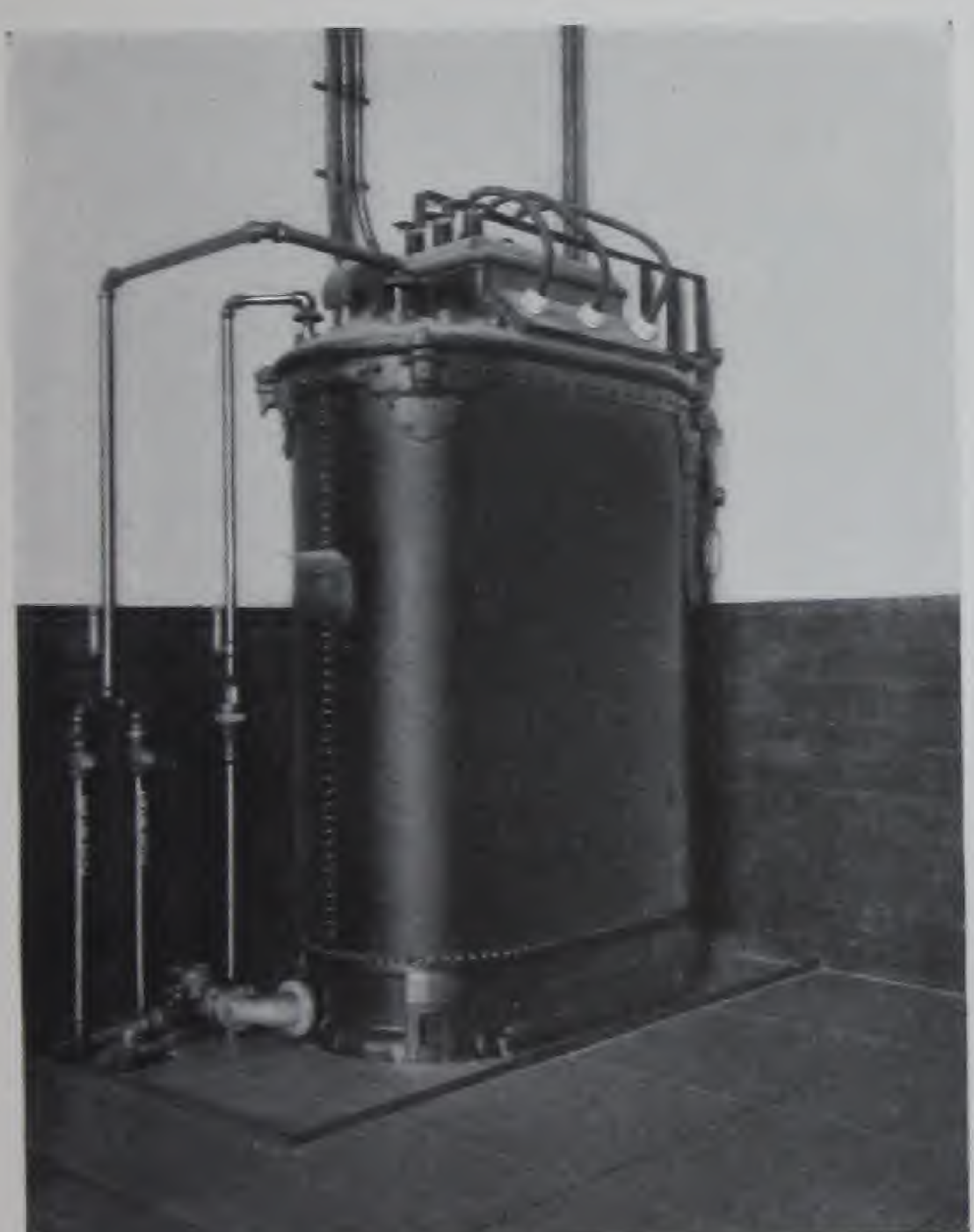
The four transformers for supplying power for the exciter sets from the main bus are of the three-phase, oil insulated and water-cooled shell type construction. They have a continuous rating of 600 kv-a. with a temperature rise not exceeding 40 deg. C., based on a cooling water supply of 6 gallons per minute at 15 deg. C. They also have a 2-hour overload capacity of 750 kv-a. with a rise of 55 deg. C. based on a water supply of 7.5 gallons per minute.

The high-tension winding consists of five coil groups, five in series for 11,000 volts, and five in parallel for 2200 volts. Similarly, the low-tension winding consists of four groups to be connected in series for 440 volts, in series-parallel for 220 volts, and in parallel for 110 volts. No other taps are provided and

both the high and low tension windings are connected in delta. The high tension winding has been submitted to a one-minute test of 22,000 volts from primary to secondary and core, and across the full winding, while the low tension winding has been tested at 4000 volts for one minute between the secondary winding and core.

The full load efficiency is 97 per cent and the regulation at 100 per cent power-factor 2.3 per cent.

The cooling coils are of wrought iron, and the connections to oil piping and vacuum system are provided for these units as for the main transformers. Each unit occupies a floor space of 7 ft. by 4 ft. 2 in. and an over-all height of 12 ft. 10 in. The total weight including the oil is 25,200 lb.



EXCITER TRANSFORMER

Main Transformers

There are nine three-phase oil-insulated water-cooled transformers of the shell type construction, one of which is for spare. They have a maximum continuous rating of 9000 kv-a. with a temperature rise not exceeding 50 deg. C. This rise is based on an ingoing water quantity of 46 gallons per minute at a temperature of 27 deg. C.

The low-tension 11,000 volt winding is delta-connected and the high-tension 110,000

9000 KV-A. MAIN TRANSFORMER

volt winding Y-connected, with the neutral brought out and dead-grounded. For bringing out the leads four high-tension and three low-tension bushings are therefore provided in the cover. No taps are provided in either winding.

The high voltage winding is very heavily insulated and has been submitted to a one-minute high potential test of 250,000 volts from primary to secondary and core, and across the full winding, while the high-tension bushings have been tested at 450,000 volts. A similar test at 22,000 volts has been applied between the low tension winding and the core.

The efficiency of the transformers at normal load is approximately 98.5 per cent. The

regulation at unity power-factor, 1.3 per cent and the reactance 5.7 per cent.

The supporting framework which holds the core and coils together, is built of structural I-beams, channels and angles. The tanks are made of boiler plate reinforced by numerous ribs and designed to withstand atmospheric pressure. On account of their large size they had to be made in two sections, an upper and a lower, which were riveted together after their arrival at the plant. The top covers are provided with gaskets, making the transformers practically air-tight. However, a four inch overflow pipe is provided and sealed with oil paper gaskets. In general, the design is such that the cover, core and leads can be lifted out of the tanks without detaching any parts, while the whole unit rests on a wheeled truck which permits moving of the transformer from its compartment out into the gate house where it may be handled by the crane.

REACTANCE COILS IN LOW TENSION SWITCH ROOM

The cooling coils are of the 1½ inch wrought iron pipe, each coil being made up in three sections, the total length being 1834 feet. They are designed to withstand a water pressure of 500 lb. per sq. in. The water for cooling purposes is pumped from the gate house by motor-driven centrifugal pumps, after which it is filtered and led to the cooling coils. A duplicate system of piping is provided, the valves and visible discharge nozzles being mounted back of the transformer compartments on the walls facing the generator room.

Each transformer requires about 10,000 gallons of insulating oil, and a complete piping system with pumping equipments has been installed for handling this between the cars, tanks and the various transformers. Large storage tanks for both filtered and unfiltered oil are installed in separate compartments in the lower tunnel below high tail race water level, the tanks being imbedded in sand as a fire protection.

There are 12 storage tanks for transformer oil, six for the good and six for the bad oil. Two oil treating outfits with the necessary pumps, filters, drying ovens, etc., are provided for filtering the oil. These are at present of the portable type, but piping arrangements are made so that permanent equipments can be installed. Connections are provided at the bottom of the transformers for filling or emptying the oil. At the bottom of the tank is also a quick acting valve accessible from the generator room, which allows the transformer oil to be quickly discharged either into the storage tanks in the substructure or directly into the tail race in case of emergency.

Each transformer is provided with an oil gauge and a thermometer of the capillary tube type.

Each transformer occupies a floor space of approximately 9 ft. by 16 ft. The height to the top of the cover is 18 ft. 6 in. and to the

top of the high-tension leads 24 ft. 3 in. The weight of the complete unit including the oil is 246,000 lb.

Power Limiting Reactances

Power limiting reactances are, as before mentioned, inserted between the low-tension busbar sections to limit to a safe value the rush of current in case of short-circuit. There are twelve reactances in four sets, each having a nominal rating of 240 kv-a., or 8 per cent in terms of the rating of one of the 9000 kv-a. generators. In other words, when the normal current of one generator flows through the reactance, it causes a drop in voltage of 8 per cent of the generator star voltage across the terminals of the reactance coil. As the generators themselves are designed for a high inherent reactance, limiting their short-circuit current to about five times normal full load current, it is obvious that the total current input into a short-circuit somewhere on the low-tension bus will be limited to about 40 times the full load current of one generator. In case of a short-circuit on any of the outgoing lines, the current rush will be still less, owing to the intervention of the transformer reactance in series with the sectionalizing reactances. In any case not more than two sections on either side of the short-circuited one will be affected, and the voltage of these will not fall below 75 per cent of the normal voltage. By means of these sectionalizing reactances it is therefore possible to confine troubles to one section and thus maintain an uninterrupted operation of the other parts of the system.

The reactance coils are provided with tap terminals, so that either 6 or 4 per cent reactances can be obtained when desired. These taps are, however, not used at the present time. The winding consists of one inch copper cable, wound so that both ends of the coil are brought to the outside in order to facilitate their connection to the busbars. The core is of hollow concrete and the winding is mounted on specially selected, kiln dried, resin treated maple supports, fastened to the concrete core by brass studs. The winding is insulated from all metal parts and the concrete core to withstand an insulation test of 33,000 volts for one minute. The temperature rise is limited to 40 deg. C. at normal operating conditions and to 300 deg. C. with fifteen times full load current for one minute. No iron or other magnetic material is used in the construction of these reactances, and furthermore they are sufficiently removed from such materials to maintain a straight voltage characteristic. The spacing between centers of coils is 78 in. and the magnetic clearances 72 in. from the center point and 26 in. from the ends. The reactances are 98 in. high, 56 in. in diameter, and weigh about 9000 lb.

Switching Equipment

The arrangement and sectionalizing of the busbars was described under the section "System of Connections" and a clear understanding of the switching equipment and the system of connections can best be obtained by reference to the general wiring diagram on page 11 insert.

All the switches, with exception of those for sectionalizing the low-tension busbars, are of the non-automatic type. On account of the double busbar arrangement, double generator and transformer switches, as well as line switches, are provided. The generator switches have a capacity of 500 amperes, and the low-tension transformer switches 800 amperes.

The automatic low-tension bus-section switches, which have a capacity of 2000 amperes, are opened by definite time limit relays actuated from current transformers in the outgoing lines and by inverse time limit relays in the main transformer leads. In this manner trouble on one section merely opens the two section switches and thus confines the trouble to the affected section. The relay settings, however, are adjusted to limit currents to values below those which would injure transformers, and also to limit the time during which line currents can supply an excessive arc. An arrangement is also made whereby the opening of the section switches

LOOKING SOUTH THROUGH LOW TENSION BUS ROOM

will cause resistance to be inserted in the fields of the exciters for the short-circuited section, reducing the generator voltage to less than half of its normal value. This result is

LOOKING NORTH THROUGH LOW-TENSION SWITCH ROOM

accomplished by special relays which open short-circuits across extra exciter field resistances. By this arrangement a certain class of troubles, such as arcing ground, etc., may be cleared through lack of potential without even causing the synchronous machinery on the system to fall out of step.

There are in all 74 low-tension oil switches which are of the H-6, motor-operated type with 10 in. pots mounted in concrete cells. Disconnecting switches are provided on both sides of every oil switch. These switches are mounted in sub-cells below the oil switches, and are equipped with locking devices to prevent accidental opening. The disconnecting switches for the reactances are mechanically interlocked with the sectionalizing oil switches so that they cannot

VIEW OF LOW TENSION BUS COMPARTMENTS

be opened or closed until the oil switch is first opened.

The high tension switches, of which there are 21, are of the K-15 solenoid-operated type. Each switch has a capacity of 400 amperes, weighs 24,400 lb., occupies a floor space of 6 ft. by 17 ft., and has a height of 10 ft. The tank contains 1375 gallons of oil. Each switch is tested at 330,000 volts. A piping system is provided so that the oil can readily be drawn off to the oil storage tanks in the basement. By means of a track which runs the full length of the high-tension bus room floor, the handling of these switches, in case of repair, is greatly facilitated. All the switch tanks are thoroughly grounded, and a complete ground system with four ground plates is provided throughout the station.

High-tension disconnecting switches are also provided, as indicated on the wiring diagram. The blades of these switches have a length of about 4 ft. They are opened by long wooden rods, which are provided with grounded rings placed above the hand of the operator. When in use these rings are to be connected to the nearest ground bus, thus protecting the operator from danger of static shocks.

The generator leads consist of 600,000 c.m. single conductor cable, insulated with 3/8 in. of varnished cambric and with a double braid flameproof covering. They are installed in fiber ducts.

The low-tension busses consist of 3/8 in. by 3 in. copper bars, mounted on insulator supports and installed in an enclosed bus structure. This structure is built up of 2½ in. moulded concrete slabs set on 4 in. concrete barriers. The inside dimensions of each bus compartment are 15 in. by 15 in. and the total length of the compartments is over one mile, requiring over three thousand slabs. Special provisions for expansion and contraction have been made in the construction of the busses, on account of their length, which is nearly equal to the full length of the station.

The connections from the low tension bus to the step-up transformers are similar to the generator leads, and are also run in fiber conduit.

SECTION OF WEST HIGH TENSION ROOM, FOURTH FLOOR

Each of the two sets of high-tension busses are installed in a separate room. They consist of 2 in. standard iron pipes, bronze painted and spaced 6 ft. apart without any barriers between. They are suspended from the ceiling by 7-unit, 10 in. suspension insulators, dry tested at 440,000 volts. The connections from the high-tension bus to the transformers consist of 1¼ in. bronze painted iron pipe, and from the bus to the outgoing lines of 1¼ in. copper pipe. The pipes are supported by 6-unit post insulators, and large vertical air shaft passages are provided for the transformer connections.

The roof bushings are of the compound-filled type, tested at 440,000 volts dry and 330,000 volts wet. From these bushings the lines run through the lightning arrester choke coils to disconnecting switches. These switches are of a rotary double-break type, with 12 ft. blades spaced 24 ft. apart. They are opened from the roof by means of a lever, and provided with horns at both ends for breaking the charging current. By means of separate ground switches the lines can readily be grounded when repairs are to be made. Both the choke coils and disconnecting switches are mounted on a roof structure of steel, which also serves as anchor tower for the long river spans.

All the apparatus and their groupings are distinctly labeled throughout the station to avoid as far as possible accidents and mistakes in operation. The piping is painted in different colors to clearly indicate to what class it belongs.

CHIEF OPERATOR'S ROOM, SHOWING CONTROL BOARD AND SWITCHBOARDS

Operating Room and Control Switchboard

All the apparatus in the station is controlled electrically from an operating room, which is at present located on the fourth floor at the south end of the present building, but which will be in the middle of the station when the extension is completed. The generator room is not visible from the operating room, but by descending a few steps to an inspection balcony a good view is obtained of it.

The operation of the station is completely controlled by a chief dispatcher, who is in telephonic communication with all parts of the system. A special desk is provided for him, on which is mounted the telephone switchboard, while in front of this desk a miniature arc-shaped switchboard is installed which contains a set of mimic busbars showing by means of small indicating lights the open or closed position of all the switches in the station. It also contains graphic voltmeters and ammeters for recording the voltage on each bus section and the current in each of the outgoing lines.

The main control switchboard is divided into six sections corresponding to the bus sections, with an additional section for the auxiliary equipment. The arrangement of these boards is at the present time in the form of an L, although ultimately it will be in the form of a U, with the dispatcher board in the center.

The different sections comprise a total of 25 panels, with one panel for each generator and transformer unit and one for the section

equipment and each outgoing line. The boards, which are made of black slate, are of the bench-type, with the control switches, indicating lamps, etc., mounted on the bench; while the instruments, generator voltage regulators, etc., are mounted on vertical panels back of the benches. The instrument equipments are as follows:

Generator and Transformer Panels

3 ammeters, 1200 amp., generator leads.
1 indicating wattmeter, 15,000 kw.
1 watthour meter.
1 wattless component indicator, 7500-0-7500 kv-a.
1 field ammeter, 600 amp.
3 ammeters, 2400 amp., transformer leads.

Section and Line Panels

1 synchronism indicator.
2 voltmeters for busses, 175 volts.
1 voltmeter for generators and transformers 175 volts.
1 frequency indicator, 25 cycles.
1 generator field voltmeter, 350 volts.
1 transformer neutral ammeter, 600 amp.
1 exciter transformer ammeter, 1000 amp.
3 line ammeters, 1200 amp.
1 exciter transformer watthour meter.

Current and potential transformers are installed in the bus and wiring compartments. Of particular interest are the large 110,000 volt current transformers inserted in the outgoing lines. Transformers are provided with a spark gap to protect them against high voltage surges, etc.

The system for transmitting signals between the switchboard and generating room is quite novel. It is similar to that which is used on the Panama canal to indicate the position of the lock machinery. The signals will be transmitted by "position indicators," which resemble to some extent small induction motors; these devices being provided with three-phase stator windings and single-phase rotor windings of the shuttle type. For operation, two position indicators are connected in multiple, the rotors being excited from a single-phase 125 volt, 25 cycle source, and the stators by induction. To send a signal, the rotor of one of the indicators is

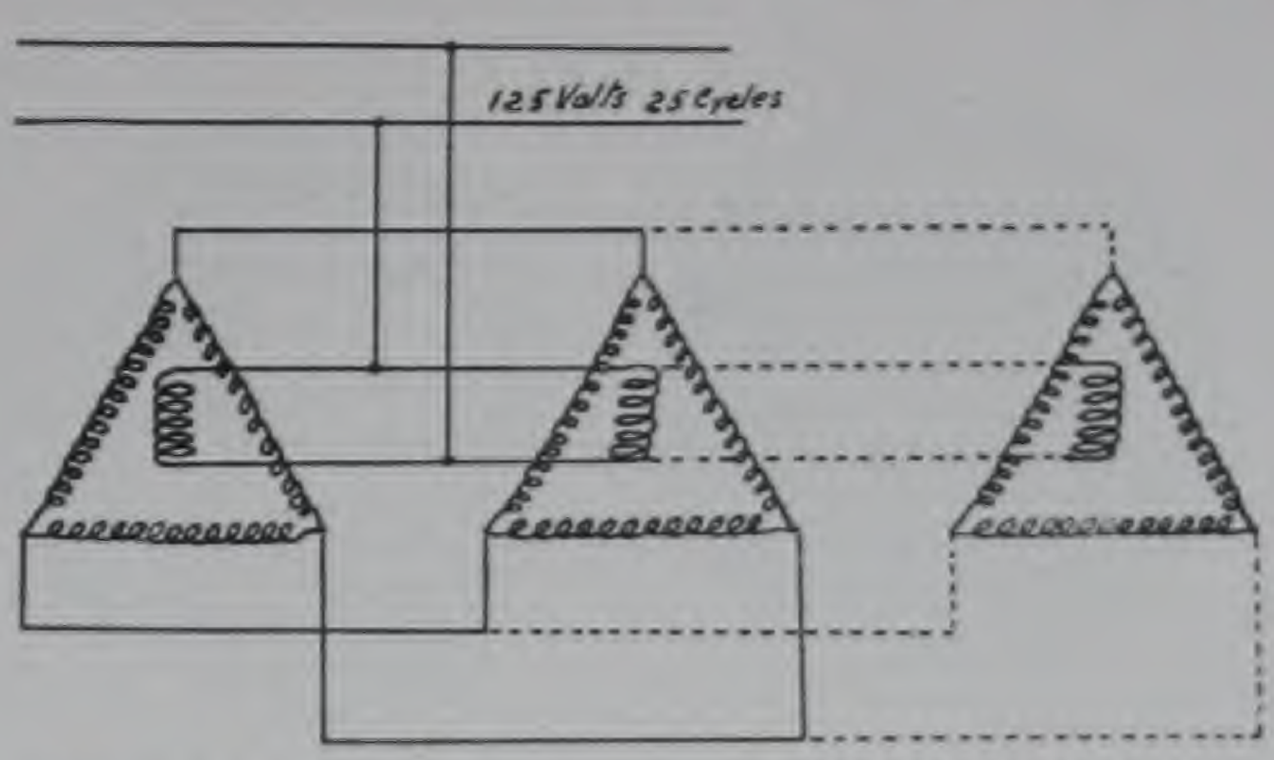


DIAGRAM OF CONNECTIONS OF TRANSMITTER AND RECEIVER

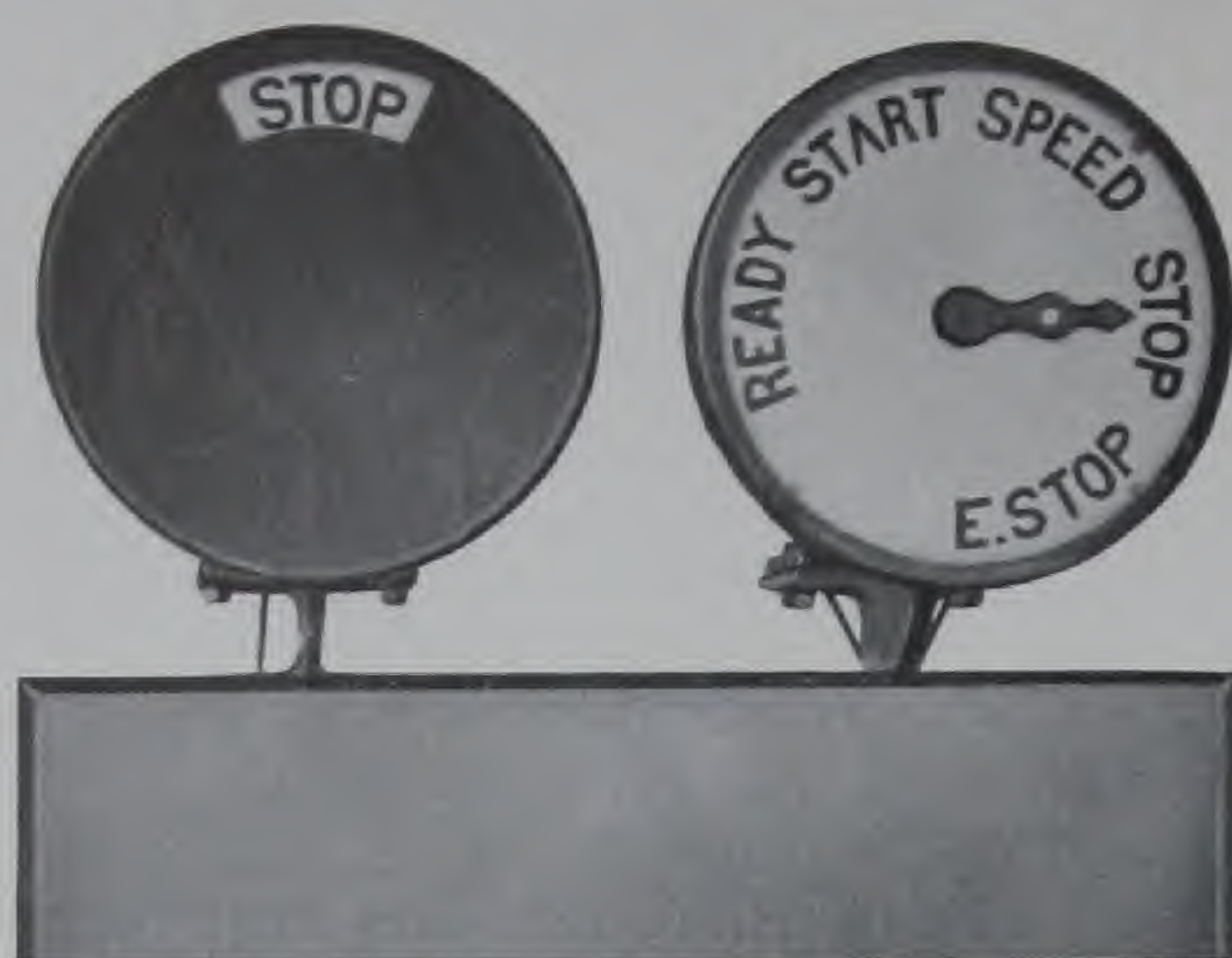
turned to any desired position, and the rotor of the connected machine or machines will assume a like position.

One transmitter and one receiver for each generator are provided on the switchboard, and also on a pedestal, located conveniently near each generator. The transmitter on the switchboard, is operated through a cable and pulley arrangement by a handle located on the front of the board concentric with the handwheel

PEDESTAL CONTAINING TRANSMITTER AND RECEIVER, LOCATED NEAR GENERATOR

which operates the field rheostat of the generator. This controlling handle is provided with a pointer which moves over the face of

an indicating dial, the dial at the right being the receiver. The dial shown at the top of the pedestal is operated by the receiver end of the position indicator, which,



RECEIVER AND TRANSMITTER FOR SIGNALLING BETWEEN CONTROL BOARD AND GENERATOR ROOM

as has already been stated, is controlled from the switchboard transmitter. The handle and pointer just below this dial are mechanically connected to the transmitter (located in the pedestal) which controls the receiver at the switchboard. On both the pedestals and benchboard, at each side of the transmitter handle, are located double push button switches which are employed for operating signal lamps, whistles and bells.

The method of signalling is as follows: When the switchboard operator desires to send a signal he turns the handle of the transmitter until its dial indicates the signal he wishes to send. This signal will be indicated on the dial of the receiver in the generator room. He then pushes the button on the right of the handle. This lights a lamp on the generator and blows a whistle in the generator room to attract the attention of the man in charge of the particular machine. As soon as the attendant has read the signal on his receiver, he will turn the handle of the transmitter on the pedestal to the same signal. He will then push the button at the right of the handle, which will extinguish the lamp and cut out the whistle. Next he will push the button at the left of the handle, which operation will light a lamp in the switchboard room and also ring a signal bell indicating to the switchboard man that the generator attendant has received the signal and also just what signal he received. The switchboard operator, after having seen this returned signal, will push the button at the left of the transmitter handle, which will extinguish the lamp and cut out the signal bell. This completes the cycle of sending and receiving a signal.

Double emergency cut-out switches are installed near all the generators, one on the main floor and the other on the exciter gallery. In case of trouble to one of the units it is only necessary to break the glass cover of the cabinet and pull the switch, which operation will close the gates and open both the main generator switch and the field switch, thus entirely disconnecting the unit.

The panels containing the circuit breakers and switches for the auxiliary generators, lighting, and other station service are located on the exciter gallery in the bays opposite the auxiliary generators.

Power for the electrical control of all the oil switches, etc., is obtained from two storage batteries, each consisting of 68 cells having a rating of 320 ampere-hours. For their charging two 15 kw., 750 r.p.m. motor-generator sets are provided.

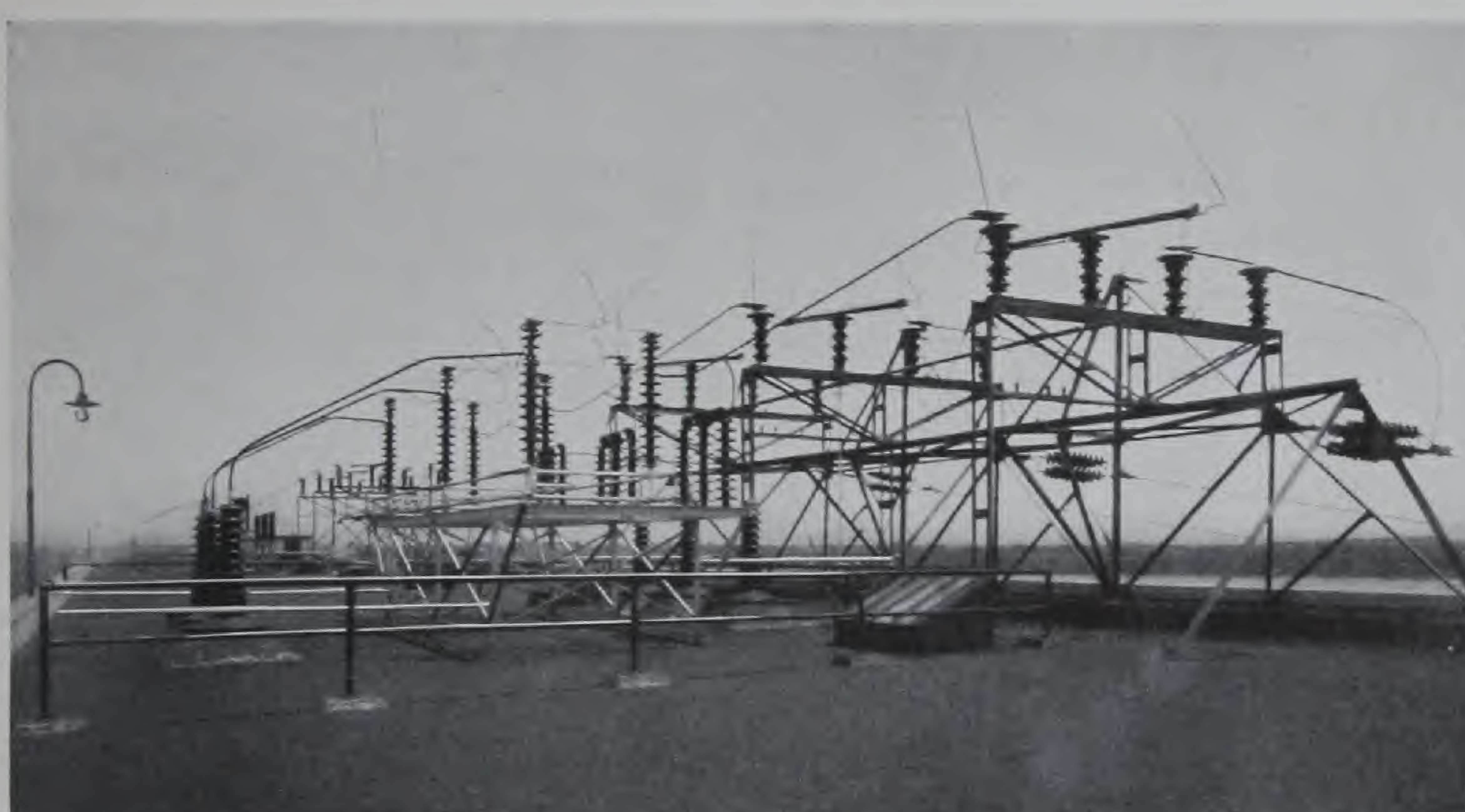
Feeder regulators are used on several of the local and station circuits. The largest of these are the two three-phase water cooled induction regulators which control the two 3000 kw., 11,000 volt Burlington lines. These regulators have a range of 20 per cent, and their operation is by motors automatically controlled by contact-making voltmeters used in conjunction with line drop compensators. A number of smaller, self-cooled, automatically operated, single-phase regulators are also used for maintaining a constant voltage on the station lighting circuits.

A very complete telephone system has been installed. Nearly one hundred instruments are provided at various points in the station

alone, and many others are installed in the substations and in telephone booths along the transmission lines.

Lightning Arresters

Two sets of electrolytic lightning arresters are provided for the two outgoing 110,000 volt lines. These arresters are installed on the fourth floor, in separate rooms with fire doors, while the choke coils and horn gaps are mounted out-of-doors on the roof structure. The taps for the arresters are taken off between the choke coils and disconnecting switches, and bushings similar to the line entrance bushings are provided for passing the connections through the roof.



ROOF STRUCTURES FOR 110,000 VOLT LINE ENTRANCES

Each arrester consists of four tanks, three of which are connected to the line wires through the horn gaps, while the fourth tank is connected between the other three and ground. The arrester gaps are of the double-horn type with charging resistances. The auxiliary horn is mounted above and insulated from the regular horn in such a manner as to intercept the arc if it rises on the regular horn. Enough resistance is connected in series with this auxiliary horn so that the current flow and arc across this gap are always limited to a moderate value. Such a device has several advantages: Since the mechanism is so arranged that the charging is always done through the auxiliary horn, the current rush is limited during the charging and thus troubles from carelessness or ignorance are avoided. It also gives a more uniform charging current. Lightning discharges will pass across the auxiliary gap through the series resistance to the cells. If the discharge is heavy, the resistance offers sufficient impedance to cause the spark to pass to the main horn. This is accomplished with only a slight increase in potential, because the gap is already ionized. If the cells are in a normal condition the spark at the gap is immediately extinguished without any flow of dynamic current. If the cells, through either negligence or some untoward condition, are in poor form, the dynamic current may follow the discharge across the main gap and the arc will rise to the safety horn and be extinguished through a resistance.

Electrolytic lightning arresters are also installed for each of the 11,000 volt bus sections.

Station Lighting and Service Equipment

The lighting in the generator room is done entirely by 500-watt tungsten lamps, other

parts of the station being illuminated by tungsten lamps varying in size from 25 to 500 watts. The current for the lighting is normally taken from the 440 volt a-c. exciter bus, from which it is stepped down to 250/125 volt by means of three 75 kv-a. transformers. Arrangements are also made so that the current may be supplied from the 11,000 volt busses through three 75 kv-a. step-down transformers. Each of the lighting feeders is provided with a 7.5 kv-a. induction regulator for maintaining a constant voltage.

As a protective measure, about one third of the lights, well distributed in the station, are arranged so that in case of trouble to the supply system they will be automatically switched over to one of the control batteries, which has sufficient capacity to operate them for about one hour.

Diffused illumination in the control room is provided by means of a skylight, which forms the entire ceiling. In order to prevent glare on the instruments it also became necessary to provide amber-colored glass in the windows. At night a diffused illumination is accomplished by tungsten lamps, which are mounted back of the skylight panes.

A complete steam heating system with water tube boilers is installed, and in connection with this there is a steam cleaning plant for waste, which necessarily is used in large quanties in a station of this magnitude.

The auxiliary power for driving the numerous pumps, cranes, etc., in the station is also ordinarily taken from the 440 volt exciter bus; but it may also be supplied from the 11,000 volt main bus through a 500 kw. three-phase, step-down transformer which is provided for this purpose.

Two 150 ton traveling cranes are installed in the generating room and a 75-ton crane in the gate house.

A complete repair shop is located in the north end of the building, and ample store rooms are provided on both the main floor and the upper floor. Both freight and passenger elevators are provided, and spacious offices are located near the control room in the south end of the building.

There are locker and modern toilet rooms in several parts of the building, and both a vacuum and air pressure system for cleaning. Two complete water systems are installed, one for the transformer cooling, utilizing a pair of 5 in. duplicate headers extending the full length of the building, and the second for the house service.

Transmission Lines

The bulk of the power is, as before mentioned, transmitted at 110,000 volts to St. Louis, a distance of about 144 miles from Keokuk. Several substations are, however, installed along this line for tapping off branch lines through which power is transmitted to other communities at lower voltages. For local consumption and for the territory north as far as Burlington, a distance of about 37 miles from Keokuk, the power is transmitted at 11,000 volts. A map illustrating the territory served by the various transmission lines was shown on page 2, while the above table gives the respective lengths and transmission voltages.

Line	Length in Miles	Voltage
Keokuk-St. Louis	143.6	110,000
Meppen-Alton	28.7	66,000
Hulls-Ilasco	8.3	33,000
Hulls-Quincy	19.3	33,000
Keokuk-Burlington	37.0	11,000
Keokuk-Mooar	5.8	11,000

Keokuk-St. Louis Line

This is a double-circuit steel tower line built on a 100 ft. private right-of-way, providing room for another future line. The normal span is approximately 800 feet, while the longest span, which is across the Missouri River, is 3180 ft. Strain towers are used at all angles, on both sides of railroad crossings, and for approximately every tenth tower on tangents.

The towers are all of the four-legged construction, the standard type having a total height of 79 feet and a base measurement of 20 by 20 ft. Its weight is 6800 lb., and it is designed to withstand the weight and side strain of all the conductors under the most severe weather conditions, besides the unbalanced pull caused by the breaking of two of the conductors.

The strain towers, to which the conductors are dead ended, have a total height of 74 ft., a width at the base of 24 by 24 ft., and a weight of 10,500 lb. These towers are designed to withstand the unbalanced pull caused by the breaking of all the seven wires.

The line conductors consist of a 19-strand medium-drawn copper cable having a diameter of 5/8 in. and an area of 300,000 c.m. The three wires of each circuit are arranged in nearly a vertical plane at elevations of respectively 50, 60 and 70 ft. above the ground; the two circuits being suspended on opposite sides of the towers, with a spacing of about 18½ ft. The top wires are slightly closer together than the bottom ones.

ST. LOUIS TRANSMISSION LINE. CABLE STRUNG ON LINE OF STANDARD TOWERS

The cable has an ultimate strength of 14,000 lb., which gives a factor of safety of two under the worst load conditions, which are assumed to be a one-half inch coating of ice, a 60-mile wind, and 0 deg. F. For an 800 foot span, this corresponds to a load of not more than 7000 lb. The corona voltage is approximately 150,000, which gives a wide margin above the normal operating voltage.

The suspension insulators on the standard towers consist of single strings of seven 10 in. disks in series, while at the anchor towers each conductor is fastened rigidly to the structure by two parallel strings, each consisting of eight 10 in. disks. The conductors are looped under the crossarm of the anchor towers. The suspension insulators have been subjected to a rain test of 330,000 volts and a dry test of 440,000 volts.

The ground wire, which is a ½ inch 7-strand galvanized Siemens-Martin steel cable, is mounted at the apex of the towers. Its ultimate strength is 11,000 lb. with a factor of safety of two.

All towers are provided with heavy reinforced concrete foundations. Those for the standard towers extend 6 ft. below ground and weigh about 2 tons per leg, while strain tower foundations extend 8 ft. below ground and weigh approximately 7½ tons per leg.

The transmission line crosses the Mississippi River twice and the Missouri River once, the spans varying from 1950 to 3180 feet, with a minimum clearance to the water surface of 70 feet. At each crossing the two circuits are separated and each circuit, together with a ground wire, is carried on separate towers. The first crossing is at Keokuk, where the span has a length of 2820 feet, extending from the roof structure on the power house to strain towers on the opposite shore, each having a total height of 145 feet and a weight of 88,300 lb.

The second crossing is at Brussels, where the river divides into three channels. Each circuit is carried across on three 160 ft. towers located on islands, the span varying from 1950 to 2400 feet. These towers, which weigh 76,400 lb. each, are only of an intermediate type, and the lines are dead-ended by means of lower anchor towers on the river banks.

ST. LOUIS LINE, RIVER-CROSSING TOWERS

The crossing of the Missouri River necessitates one span of 3180 feet and another of 2350 feet. The highest tower, which is located on an island at the midpoint of the crossing, has a total height of 230 ft., while the tower on the higher south bank of the river is 190 ft. high. The former tower weighs 107,400 lb. and the latter 84,700 lb. Both towers are of the intermediate type, the lines being dead-ended to the next ones, which are 60 ft. high and of the anchor type. All these river crossing towers are set on massive concrete foundations resting on bed rock, piles, or earth.

The conductor used for all these long spans consists of a 5/8 in. 19-strand core of special high-tension steel, with an outer stranding of 20 No. 10 B.&S. hard drawn copper wires, making a total diameter of 7/8 inch. They are rigidly fastened to the tower structures by a group of six parallel insulator strings, each consisting of eight 10-inch disks. A system of equalizing levers is provided for dividing the strain equally among the six strings. The ultimate strength of the conductor is 52,000 lb. and of the insulator banks 60,000 lb., which, under the worst load conditions of 24,000 lb., gives a safety factor of more than two. In order to prevent the swinging together of the wires, the conductors are spaced 20 ft. apart in a horizontal plane, with the ground wire above. These ground wires, which are similar to the steel core of the line conductors, serve as supports for the telephone wires and also as runways for the cable cars which are used for the inspection and repair of the spans.

RIVER-CROSSING INSULATOR

For railroad crossings the conductors are dead-ended at the first two towers on each

side of the track, the outside ones of which are of the anchor type. The conductors in these three spans are strung only at half normal tension, and in other respects the N.E.L.A. recommendations for railroad crossings are followed.

Each of the transmission circuits has a capacity of 45,000 h.p., with a voltage drop of 10 per cent and an energy loss of approximately the same amount.

A telephone line parallels the transmission line for the entire distance from Keokuk to St. Louis. It is built on one side of the right-of-way and consists of two No. 8 telephone conductors and a ground wire mounted on 30 ft. cedar poles with a spacing of 125 ft. Houses for the patrolmen are provided every 18 miles and telephone booths every 4 miles. Special precautions have been taken to insulate the telephone lines, and the protective equipment for the telephones consist of drainage coils, vacuum and multigap arresters, and fuses and insulating transformers.

66,000 VOLT LINE TO ALTON, LOOKING TOWARDS ILLINOIS RIVER CROSSING

Meppen-Alton Line

This is a single circuit 66,000 volt line branching out from the main line at the Meppen substation and running as far as Alton, a distance of 28.7 miles. The conductors are supported on H-frame wood structures spaced 300 ft. apart. The structures consist of two cypress poles 6 in. in diameter at the top and 45 ft. high, and a wooden crossarm of two pieces 2 in. by 8 in. by 16 ft. Three No. 2 stranded copper conductors are supported in a horizontal plane by 4-disk suspension insulators and the two $\frac{5}{16}$ inch Siemens-Martin galvanized steel stranded ground wires are carried on the top of the poles. The two No. 8 copper clad telephone wires are supported on brackets on the sides of the poles.

This line crosses the Illinois River, necessitating four spans from 1160 to 1800 ft. in length. Five steel towers are used for these, having a height of 104 ft., a width of 34 by 34 ft. at the base, and weighing 36,800 lb. The line conductors here consist of $\frac{5}{8}$ in. Monitor steel strand, supported from the middle crossarm by three parallel 4-disk insulators. The ground and telephone wires are of $\frac{3}{8}$ in. high-tension steel, the former being supported from the upper crossarm and the latter from the lower crossarm by two parallel 4-disk strings.

Hulls-Ilasco Line

The length of this line is 8.3 miles and the transmission voltage 33,000. The line consists of two single circuits of three No. 2 B.&S. stranded hard-drawn copper conductors mounted on pin type insulators on 40 ft. Idaho cedar poles spaced 140 ft. apart. A $\frac{1}{4}$ in. galvanized stranded steel ground wire is mounted on the top of the poles, and two No. 8 B.W.G. galvanized iron telephone wires are carried on a crossarm below the two crossarms carrying the line conductors.

This line also crosses the Mississippi River in two spans of 1650 and 2850 ft. lengths. Three steel towers are used for these spans: a 60 ft. tower on the Illinois shore, and two 190 ft. towers, one on King's Island and the other on the Missouri shore. The latter tower is of the anchor type with a base 50

ft. square and a weight of 122,870 lb., while the other 190 ft. tower is of the intermediate type with a base of 42.5 ft. square and a weight of 96,260 lb. The line conductors, which consist of $\frac{5}{8}$ in. stranded Monitor steel cores surrounded by twenty No. 10 copper wires, are rigidly supported by 6-string 8-disk insulator groups, as were the river spans of the St. Louis line. Similarly, the two ground wires are of $\frac{5}{8}$ in. Monitor steel and serve as supports for the two No. 8 telephone wires.

Hulls-Quincy Line

This is also a 33,000 volt single circuit branch line with a length of 19.3 miles. The three No. 2 stranded copper wires are carried on pin type insulators on 40 ft. Missouri cypress poles, spaced 140 ft. apart in the country and 125 ft. inside the Quincy city limits. A $\frac{1}{4}$ in. Siemens-Martin steel strand ground wire is carried along the top of the poles, except inside the city limits, where it is supported above the poles on a channel iron support.

Two No. 8 hard drawn bare copper wires are used for the telephone circuit, which is carried on crossarms below the conductors, except on the stretches where the line parallels the St. Louis line, in which case it is carried on the telephone poles of that line.

Keokuk-Burlington Line

This line extends northward from the substation in Hamilton, to which power is fed from the generating station through lead-covered cables carried across the dam in fiber ducts. The distance to Burlington is 37 miles and the transmission voltage is 11,000. The line conductors consist of six 19-strand, 4/0 equivalent aluminum cables carried on pin insulators which are mounted on 40 ft. Idaho cedar poles spaced 140 ft. apart. These poles are provided with three crossarms, two of the line conductors being mounted on the upper and four on the middle while the lower serves for supporting the two No. 8 B.&S. copper wires constituting the telephone circuit. A ground wire of $\frac{5}{16}$ in Siemens-Martin galvanized steel strand is carried above the tops of the poles by 3 in. steel channels. The line is grounded every fifth pole.

Keokuk-Mooar Line

Power for local distribution in the vicinity of Keokuk is also carried through lead-covered cables from the power station to a cable terminal house on the west side of the railroad tracks. In this building the lead-covered cables are terminated and the lines conveyed overhead from this point.

The Mooar line, for supplying power to the DuPont Powder Works, is of single circuit, 11,000 volt construction and has a length of 5.8 miles. Where it passes through the country, the poles, which are Missouri cypress, have a height of 35 ft. and are spaced 140 ft. apart, while through the city alleys they have a height ranging from 40 to 60 feet with a spacing of 125 ft. The three No. 2 copper conductors are all carried on one crossarm 5 ft. below the No. 6 galvanized steel ground wire, which is carried along the tops of the poles.

No transpositions are made on the 110,000 and 66,000 volt transmission lines, but the 33,000 and 11,000 volt lines are transposed every third mile. All telephone circuits are transposed every fifth pole.

SUBSTATIONS

St. Louis Substation

This station, which is by far the largest on the system, was built and is owned and operated by the Electric Company of Missouri, formerly known as the Mississippi River Power Distributing Company. The station has a capacity of 60,000 kw., and the power is distributed to two large customers, the Union Electric Light & Power Company and the United Railways Company. It is a brick structure laid out in the form of a T, with a length of 219 ft., a maximum width of 150 ft., and a height of 60 ft.

There are four 110,000 volt incoming circuits, as each of the two Keokuk lines are

split up into two circuits about a ¼ mile from the station. These circuits enter through roof entrance bushings and connect through line switches with a high-tension bus, which is divided in four sections separated by oil switches, each circuit feeding one section. The low-tension bus is similarly divided into four sections, with an additional connection forming a ring bus. Four transformer banks are provided, one for each section.

The high tension bus is normally sectionalized in the middle, while the low tension bus has all the sectionalizing switches open so that there are four separate groups of feeders on the low tension side. Two of these supply the Union Electric Light & Power Company and two the United Railways Company. One group in each pair is tied together on the high-tension bus to one transmission line, so that both these companies have two separate sources of supply all the way back to the generating station. Furthermore, as either line is capable of transmitting the full load of the station, no interruption to service will result in case one line is temporarily out of service.

COOLING BASIN FOR TRANSFORMER CIRCULATING WATER, ST. LOUIS SUBSTATION

All the outgoing feeders for the United Railways Company are three-phase, 25 cycle, 13,200 volt circuits. In addition this Company has installed the substation two 2000 kw., 375/600 volt rotary converters with air blast step-down transformers for supplying power to the territory nearest the substation, and additional space is provided for two future units.

A number of the outgoing lines of the Union Electric Light & Power Company are also three-phase, 25 cycle, 13,200-volt circuits. This Company has, however, installed a 5000 kw., 25/60 cycle frequency changer set with step-down transformers, and space is provided for a future set. The 25 cycle motor is wound for 6600 volts and the 60 cycle generator for 4400 volts, with the neutral brought out. The generator is connected to a double set of 4-wire busses, which supply power to a number of 60 cycle, single-phase outgoing feeders provided with induction regulators. A group of three 3000 kw., single-phase, 60 cycle, 4400/13,200 volt step-up transformers are also provided for supplying 60 cycle power to the territory farthest away from the station.

The high-tension apparatus is located in that portion of the building corresponding to the stem of the T, and the rotating machinery in the transept. The four incoming line switches are installed on a gallery, while the high-tension transformer and section switches are placed on the main floor and below the busbars, which are suspended from the roof trusses.

The transformers are placed in compartments along the west side of the high-tension room. These compartments are provided with rolling sheet iron doors in the outside walls, so that in case of repairs the transformers may be carried outside and placed on a transfer truck which runs to the end of the building, where they are taken into the repair room.

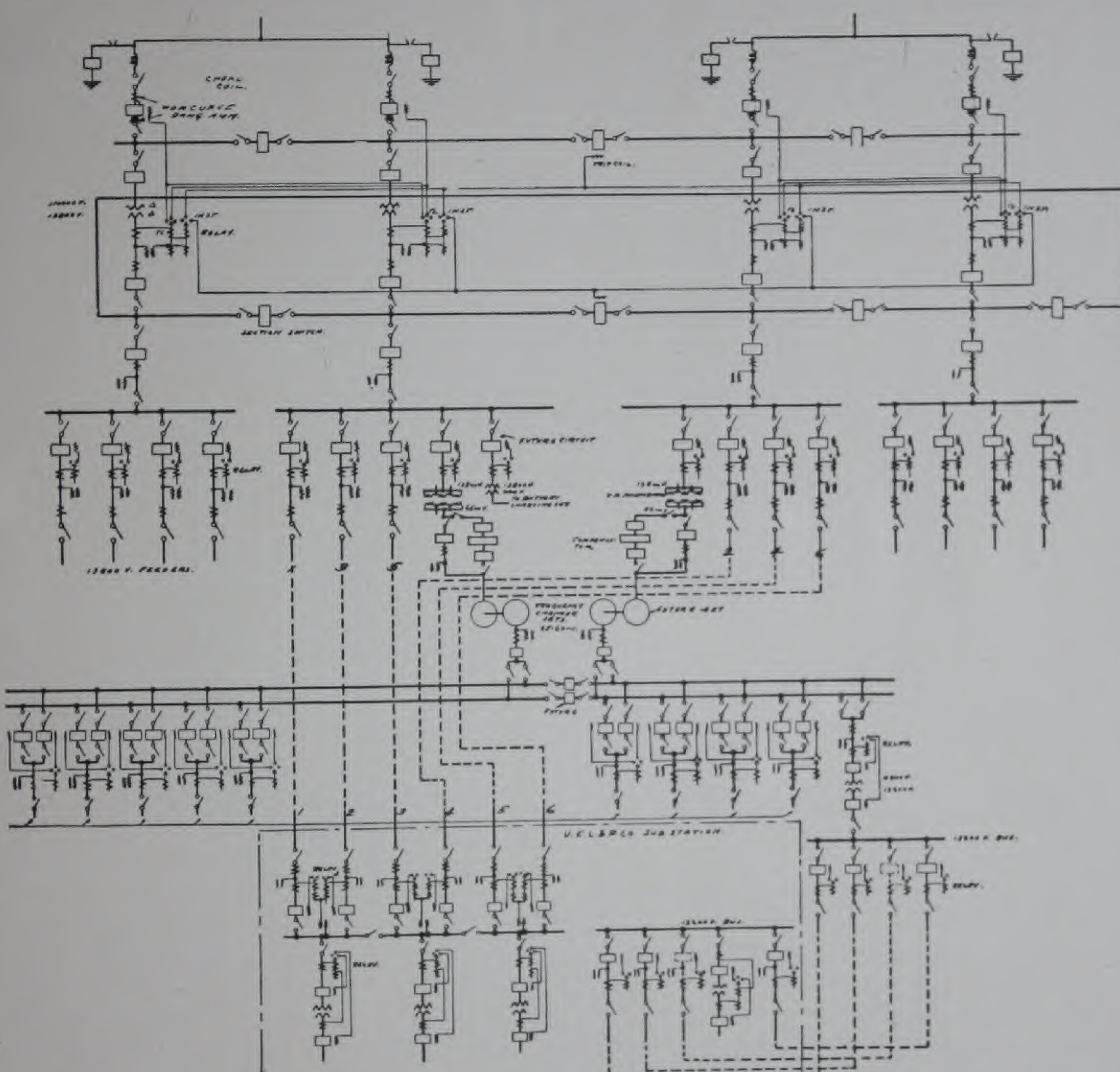
The low-tension oil switches are installed underneath the gallery in the high-tension room, and the busses beneath in the basement, while the control board is located on the gallery facing the machine room.

There are four main transformer banks, each consisting of three 5000 kw., 95,000/13,800 volt, delta-delta connected, single-

45011-34 The Mississippi River Hydro-Electric Development at Keokuk, Iowa

ST. LOUIS SUBSTATION

phase, water-cooled transformers. Each transformer requires about 5000 gallons of oil and weighs complete about 57 tons. A large cooling basin is provided a short distance from the station. It has not been found necessary to use spray, and provision is made simply for the radiation of the heat from the water to the air. Approximately 36 hours is required for the water to circulate through the cooling basin, two motor-driven pumps being provided for pumping the water. The oil drain is piped through a quick-opening valve to an oil tank in the basement. There is one tank for each transformer bank. These tanks are installed in the basement in fireproof compartments provided with iron doors. In order to make sure that these compartments are kept clean, and to obtain better ventilation, their doors are normally held open by weighted chains. These chains are provided with a fusible link which melts in case of fire and closes the door



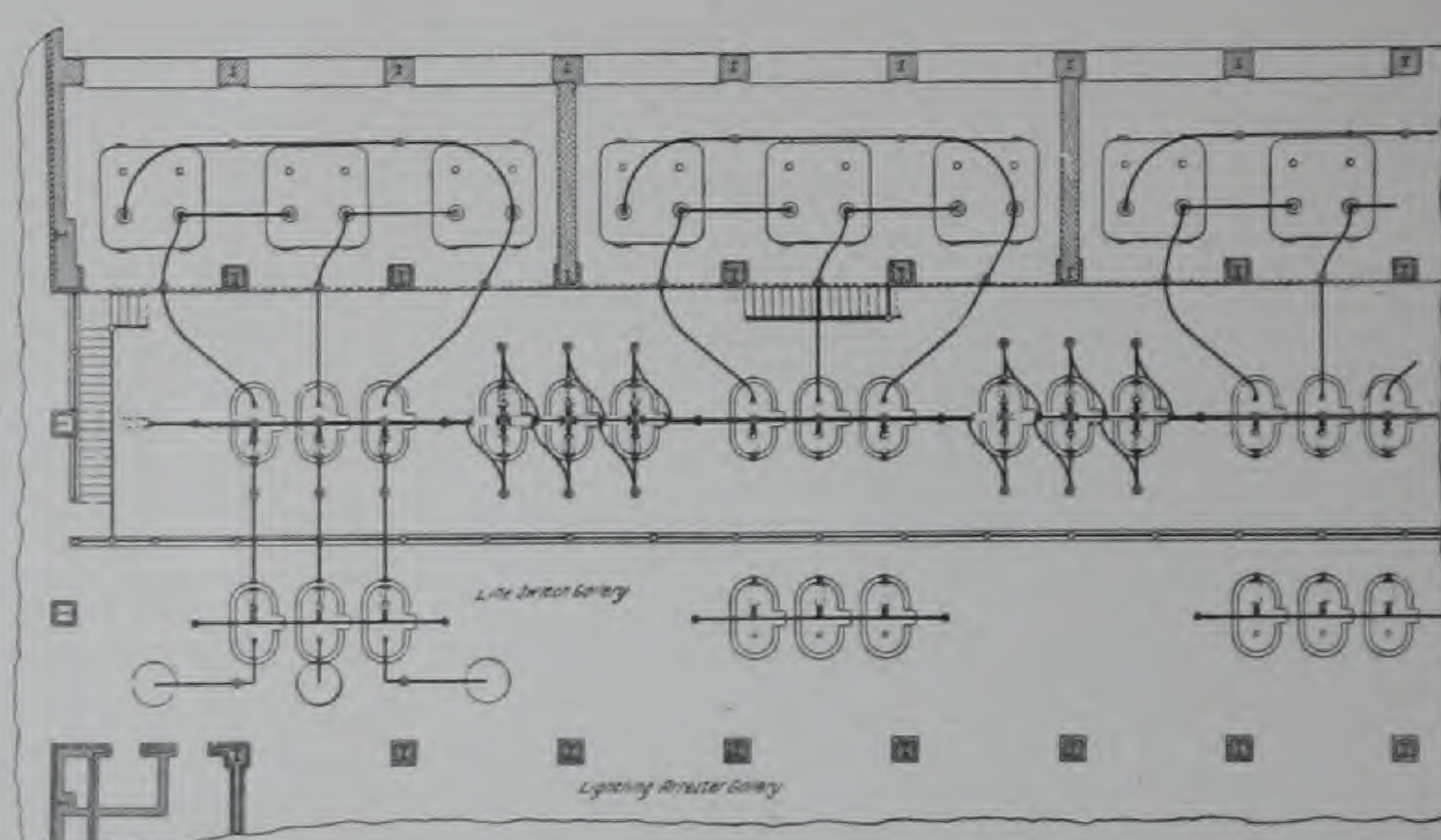
WIRING DIAGRAM, ST. LOUIS SUBSTATION

A filter press is provided for cleaning the oil.

The incoming circuits are anchored to a structural steel roof, which also supports four line disconnecting switches. These switches are of the motor-operated type, controlled from the switchboard in the station. Provisions are also made on the roof for grounding the lines by special pull-type grounding switches.

All the high tension switches are of the solenoid-operated type, and the low-tension switches of the motor-operated type. The operated, however, the high-tension bus is normally sectionalized in the middle and all the low-tension section switches are open. The effectiveness of this protective system has been fully demonstrated. During the only case of line trouble which has occurred, a dead short-curcuit on the line was handled by the automatic equipment without any interruption whatever in the delivery of the full amount of power being taken at the time by each receiving company.

Disconnecting switches are provided for isolating the oil switches. The low-tension



PARTIAL PLAN OF ST. LOUIS SUBSTATION

equipment provides two parallel reverse energy relays in the low-tension leads of every transformer bank. One of these relays, which is of the instantaneous type, trips the middle sectionalizing switches of both the high- and low-tension busses, while the other relay, which has a time element, trips the high-tension line switches. In case of a short-circuit in one of the lines, power will be fed into this both from the generating station at Keokuk and from the Union Electric Light & Power Company's 20,000 kw. steam station in St. Louis. In such a case the bus sectionalizing switches will open first, due to the instantaneous action of their relays, and thereafter the line switch of the faulty line, thus cutting out this line without disturbing the operation of the other. As usually type is of the ordinary switch blade design, but the high-tension switches are of a special plug-type design, making it possible to reduce the width of the switch room about 36 feet. These plug-type switches consist of vertical sliding rods with concentric spring contact blocks similar to those of the familiar H-3 oil switches. The rod can be firmly locked in the closed position by means of a bayonet joint.

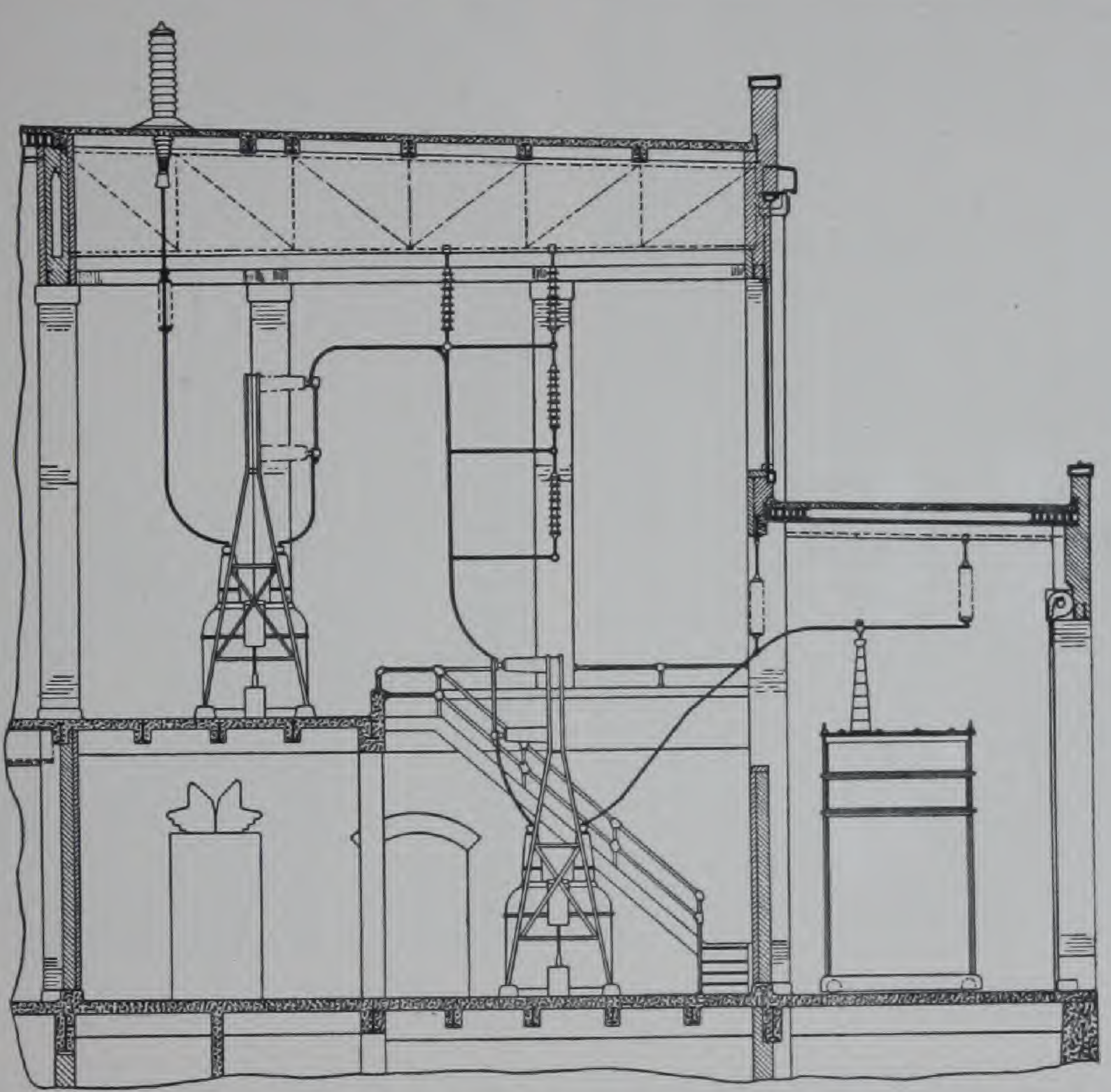
The high-tension busbars consist of 1 in. copper tubing, supported in a vertical plane from the roof trusses by means of suspension insulators comprising eight 10-in. disks, the different sections being separated by strain insulators consisting of ten 10-in. disks. All the high-tension connections are also of 1 in. copper pipe, except the leads from the trans-

former switches to the transformers, which are of iron pipe.

The low tension main and group busses consist of copper bars mounted on insulators in concrete compartments in the basement. The ring connection for the main bus consists, however, of cables drawn through fiber ducts in the wall back of the bus compartments, this arrangement resulting in a considerable saving of space. All the low-tension connections, furthermore, consist of cable run through fiber ducts in walls and floors, and provided with fireproof coverings in the manholes. The low-tension connections in the transformer compartments are encased in concrete columns. This serves both as a support for the leads and as a protective feature. All the outgoing feeder circuits for the city service leave the station through underground lead-covered cables while the county service is supplied through both overhead and underground circuits.

The control switchboard is of the ordinary benchboard construction. In addition to this there are four terminal or meter boards, one for each bus section. These boards are located in the low tension switch room adjacent to the feeder circuits which are to be measured, and graphic-recording and integrating meters are mounted thereon instead of on the benchboard. This reduces the running of a considerable amount of instrument leads to the main switchboard, and results in a great saving in both control wire and conduit. Interconnections are also made between the terminal boards, so that if it is desired at any time to record the output of one board on the meters of another board, this can readily be accomplished.

All the transformer and switch banks, etc., are thoroughly connected to the ground system, which consists of pipes driven into the ground under each building column, with



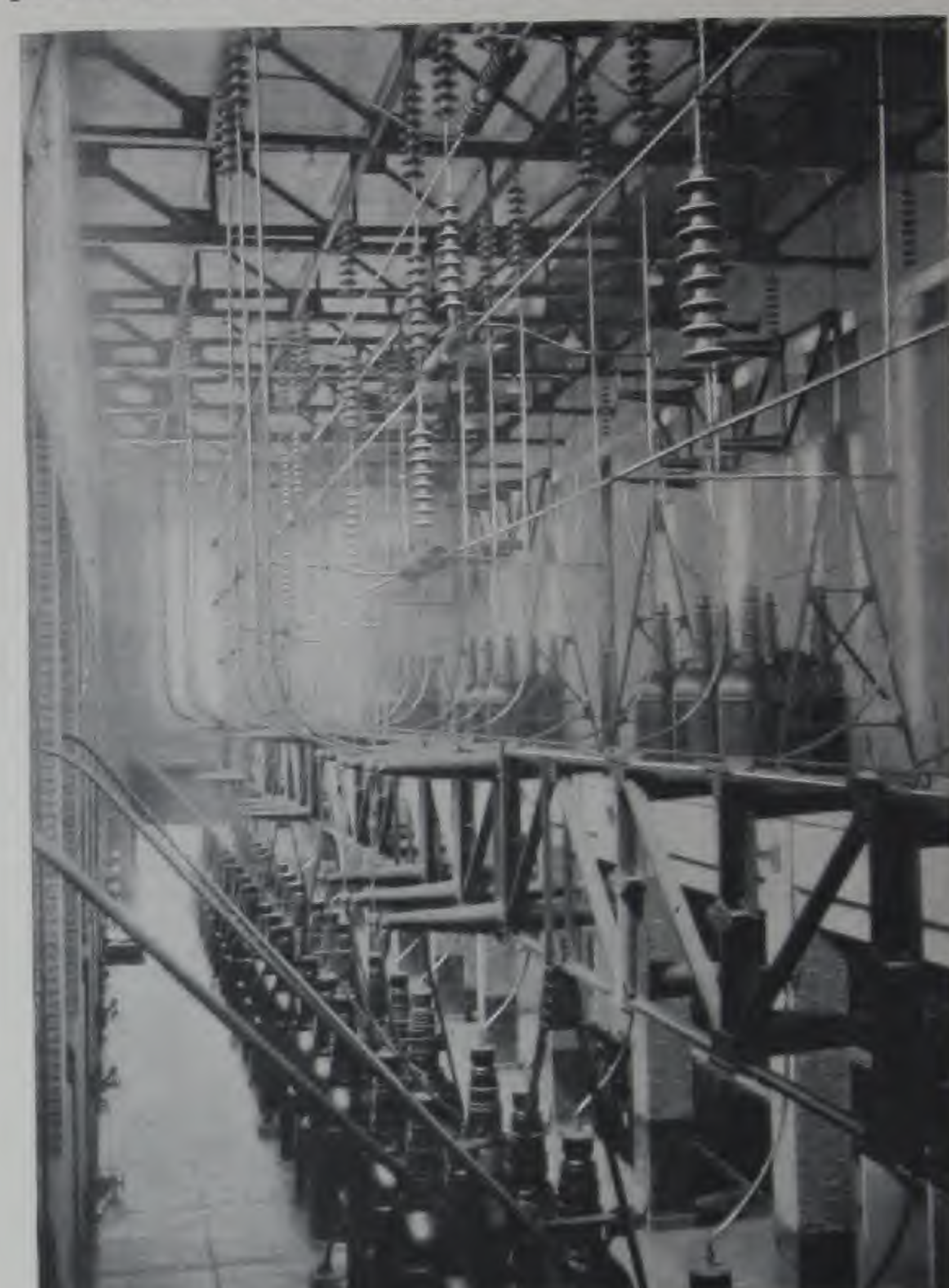
PARTIAL SECTIONAL ELEVATION, ST. LOUIS SUBSTATION

bare copper wires carried around to various parts of the building.

Current for the oil switch operation is obtained from a storage battery, a small motor-generator set being used for charging the battery.

building to move the large transformers with block and tackle and to pull the transfer trucks along the track. Pumps are provided for draining the basement in case it should get flooded, and a compressed air system is provided for cleaning purposes. This system

5000 KV-A. TRANSFORMER IN ST. LOUIS SUBSTATION



HIGH TENSION OIL SWITCH GALLERY ST. LOUIS SUBSTATION

is quite novel in that the compressed air is carried around the station through the iron pipes which are used for railings in the various rooms and galleries. This has resulted in a material saving in the amount of pipe used.

Four electrolytic lightning arresters are provided for the incoming lines. They are of the same design as those for the generating station; the tanks being placed indoors, while the horn gaps and choke coils are mounted on the roof. Each of the four low-tension bus sections is also equipped with an arrester of the electrolytic type.

The auxiliary equipment in the station is very complete. A bank of three 50 kv-a., 13,200–200/110 volt transformers, with one spare unit, is installed for supplying current to the light and power circuits in the station. A large crane is provided for handling the heavy machinery in the low-tension machine room. It can be run out of the building onto a steel trestle, and is also used in connection with the tracks and turntable outside the

Other Substations

There are a large number of other substations which have been built and which are operated by either the Mississippi River Power Company or their customers. These are located at Meppen, Alton, Hull, Ilasco, Quincy, Hamilton, Warsaw, Fort Madison, Dallas City, Burlington, Keokuk and Du Pont. The equipments and system of connections of these stations are clearly illustrated in the diagram on accompanying insert.

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